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Search in real-world routes

by

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ABSTRACT

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SEARCH IN REAL-WORLD ROUTES

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The structural nature of the world often provides a clear guide to where sought objects are likely to appear, as well as the kind of objects they may repeatedly appear in the presence of. The relationship between the targets, distractors and the landscape provides context, which ensures efficient search. This thesis will explore the dynamics of how knowledge of the environment ahead will inform search on future presentation of those scenes, as well as explore how several factors between individuals (such as cognitive resources, or tendencies towards anxiety) may influence search and learning processes. This thesis reports three studies using a new eye movement experimental paradigm termed the repeated scenes search task (RSST). This task presented scenes taken on a route around a suburban neighbourhood as search arrays, while participants searched for target superimposed in naturalistic locations. The scenes were presented on 8 occasions in each experiment, and performance improved with number of repeats. In the experimental chapters the influence of scene order on search was examined with targets appearing in several contingencies with relation to scene identity and compared between the scenes appearing in a consistent or randomised order. Subtle benefits to search were found when scenes were presented in a consistent order. The influence of boosting WM and inducing a state of anxiety upon participant responses (via more efficient eye movements) were also examined. The impact of these findings upon the general literature and with regard to individuals searching in dangerous environments are discussed, with the key finding that attentional networks, working memory and a state of anxiety are important factors to consider in search through familiar environments.

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I, ...

declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

....

....

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Chapter 1 Introduction

1.1 General introduction

Visual search (hereafter simply termed as “search”) is the act of seeking out targets present in the visual field. Successful search will depend both on visual information directly received by the visual field (bottom-up factors) as well as knowledge about the scene, context and target (top-down factors). The speed and efficiency with which humans find targets depend on processes that integrate information from and about the environment. The environment presented to us is usually static in nature, with increased familiarity with particular areas allowing us to project ourselves forward, and plan for details in the upcoming scene. The information gained from earlier experience will likely improve search efficiency, and which may be accessible even before we have seen the scene in front of us. This thesis will explore if (1) being able to predict future scenes from the real-world influences search, and (2) if it does, what cognitive and psychological factors best support or hinder this ability? The importance of this issue is that there are situations in the real world, such as routes being patrolled by soldiers scanning for improvised explosive devices (IEDs), where the likelihood of and placement of forthcoming targets would be valuable information, and useful knowledge about the structure of the environment may become implicitly learned as the individual gains experience with the area.

In Chapter 1, I consider the existing literature that explores visual search for targets, how the mechanisms of attention and working memory might allow knowledge of forthcoming scenes to enhance search for targets, and how individual variation in the functioning of these mechanisms might account for differences in search across individuals.

1.2 Visual search

Successful searches end with finding a target (termed as “hits”) or deciding on target absence (“correct rejections”). Unsuccessful searches either end in targets being missed (“misses”) or in distractors being incorrectly classified as targets (“false alarms”). The performance in search tasks is usually measured in terms of the speed and accuracy of responses.

In the search for targets set amongst distractors within otherwise empty displays, search efficiency is usually measured as the gradient between the RT and the number of items displayed on-screen (the “set size”, e.g. Wolfe, Cave & Franzel, 1989). The efficiency of search is determined by measuring how RTs and errors change as set size increases. As targets become more difficult to discriminate from distractors, the efficiency of search reduces with RT increasing and errors declining with set size.

The idea of search efficiency is challenging to apply to search in real-world scenes, as the notion of set size is difficult to use. While targets can be easily defined, the ‘distractors’ present in the scene will have different relationships to the target: some are distinctly different whereas others may be conceptually similar. Fortunately, there exists a direct measurement of search efficiency in real-world scenes that can help. This is achieved through measuring eye movements.

Saccades occur when we move the fovea from one location in the visual field to another. We make saccades due to the physiological construction of the eye and the rapid drop-off in visual acuity across the visual field. The innermost 2 degrees of the visual field correspond to the fovea, where visual acuity is highest. Outside of the fovea, the area extending to around 5 degrees of the visual field is the parafovea, and the area beyond the parafovea is known as the periphery (Rayner, 1998). Therefore, saccades are necessary in order to continuously orient the eye to objects.

The periods of relative stability between saccades are known as fixations. The average length of fixations is dependent on the task the individual is engaged in, for example; 225 ms for silent reading; 275 ms for search, 330 ms for scene perception and 400 ms for typing (see Rayner, 1998 & 2009 for reviews). These differences reflect the task demands of cognitive processing. A single, static scene may provoke several distinctive eye-movements depending on the task the participant is being asked to complete (Yarbus, 1967; DeAngelus & Pelz, 2009; Castelhano, Mack & Henderson, 2009). The saccades and fixations of eye-movements can therefore, be used as an index of visual attention.

The claim that eye movements provide an index of visual attention is not to claim that they are the same. It is possible, for example, either to make decisions without directly fixating targets, or to successfully recognise targets from the periphery (Pollatsek, Rayner & Collins, 1984; Rayner 1998). Most importantly, overt shifts of attention may be preceded by covert shifts of attention. While it is possible to shift attention without an eye-movement (Posner, 1980), for complicated stimuli an eye-movement becomes a necessity in order to orient the fovea towards the area of the visual field the stimulus occupies.

Here I make the limited claim that the deployment of attention in real-world scenes can be assessed from fixations and saccades. Alongside traditional behavioural methods (accuracy and reaction times [RTs]), the on-line record of what is attended while searching within scenes may provide a key indicator of how search might change as participants become more able to predict forthcoming scenes. Specifically, utilising eye movements allows scrutiny into any benefits to search efficiency (increased accuracy, decreased RTs) by establishing what leads to this improvement. For example, does an increased error rate occur with a decrease in whether targets are fixated, or is a decreased RT in the final result due to a shorter time in identifying the target once it is fixated (verification time)? The combination of methodologies allows for a full examination of the possibility of improved performance and the mechanisms that support the improvement.

1.2.1 Bottom-up and top-down factors that influence search

Bottom-up influences on target search occur when the stimulus properties of the visual scene draw attention (Chun & Jiang, 1998). Bottom-up factors include features of saliency (e.g. colour or brightness, Theeuwes, 1992; Bravo & Nakayama, 1992; Itti, Koch & Niebur, 1998; Itti & Kock, 2000), orientation (Moraglia, 1989); intensity (Parkhurst, Law, & Niebur, 2002), or changes in the value of a feature (e.g. luminance or motion change; Jonides & Yantis, 1988, Itti, 2005). Feature priming can also exert a bottom-up influence (Maljokovic & Nakayama, 1994; 1996; Kristjánsson, Wang & Nakayama, 2002).

Top-down influences, by contrast, are determined by the viewer. These include the matching of stored search templates to potential targets (a representation of the item being sought [or known features]), and using knowledge about scene identity to structure search (Chun & Jiang 1998; Brockmole & Henderson, 2006a, b). Top-down influences can be further categorised into explicitly and implicitly held knowledge.

To summarise, bottom-up and top-down influences on search work together to allow guidance towards targets and away from distractors (Friedman-Hill & Wolfe, 1995). In this thesis, I am concerned with exploring an additional source of top-down influence on targets presented in real-world scenes. This additional influence is the effect of being able to use knowledge about forthcoming real-world scenes to help guide search to targets. The ability to use this knowledge to guide search has not been explored previously. If this knowledge can guide search then it must be closely related to a range of other effects reported in the experimental literature. Here I consider these effects.

1.2.2 Context and memory influences in search

Of all the bottom-up influence on search, salience has been thought to have a particular importance. While saliency of scenes may contribute to the allocation of attention in many scenarios (Bravo & Nakayama, 1992; Itti, Koch & Niebur, 1998; Itti & Kock, 2000), it is not the primary factor in search tasks using real-world images (Foulsham & Underwood, 2007). This statement gains greater weight when considering real-world scenes. Work by Biederman (1972) showed that the ability to identify targets was improved when background images represented real-world images than when parts of the image were rearranged to form an unstructured scene. This effect of scene context on target detection overrides high-salience distractors in eye-movements (Henderson, Malcolm & Schandl, 2009; Henderson & Hollingworth, 1998). In fact, it has been suggested that the prevailing conclusion of saliency driving attention in scene-viewing tasks is flawed, as visually salient areas often correspond to contextually relevant information (Henderson, Brockmole, Castelhano, & Mack, 2007). Given the importance we must place on building scene memories that can provide contextual information for search, the question arises of how these memories are constructed?

Many studies have shown that held representations of scenes can be further contributed to when searching for targets in them. Despite claims to the contrary (Horowitz & Wolfe, 1998), there is evidence that we tag the distractor locations searched before finding targets. The evidence for this comes from Gibson and colleagues (2000). They asked participants to report if one or two targets had been presented in a display. The experiment contained two conditions. In one condition, the display items remained static throughout the trial. In a second condition, the display items were redrawn in new positions every 100 ms. Participant accuracy was worse in the random than the static condition, showing that participants must have marked the location of distractors dismissed as non-targets during search (Gibson, Li, Skow, Brown & Cooke, 2000). Additionally, there is some evidence that targets initially dismissed as distractors are more likely to attract refixations than previously unfixated distractors are to attract fixations (Peterson, Kramer, Wang, Irwin & McCarley, 2001). Finally, when a target is relocated to an area previously occupied by a distractor (at brief intervals, using a mask in between frames) it takes longer to find compared to its remaining in place between mask presentations, evidencing that memory for distractor locations also endures across search (Kristjánsson, 2000).

Change-detection tasks (in which aspects of the scene are changed during a saccade and often when the participant is fixating another area of the scene) provide further evidence of memories being constructed as participants search through scenes. Hollingworth and Henderson (2002) reported that participants were able to respond to changes to targets following an initial fixation to the target location. The changes were better detected when the object change was to a new category of object than one drawn from the same category (see Võ, Zwickel & Schneider, 2010 for a related finding). Additionally, changes to objects that did not have a semantic relationship to the background scene were more likely to be noticed by participants than semantically consistent objects (Hollingworth, Williams & Henderson, 2001).

Overall, these findings demonstrate visual processing operating during search contributes to the representations of scenes that we commit to memory. A consequence of this is that the act of searching provides a mechanism that underpins incidental scene learning. Castelhano and Henderson (2005) showed this directly by exploring the encoding of real-world scenes in two different tasks: search for targets or scene encoding for future recall. In both groups, participants performed above chance on discriminating scenes and their mirror reversal, and there was no difference between conditions. It is already known that greater exposure with target identities will lead to improved speed and accuracy (Henson, 2003; Horner & Henson, 2008), and many other aspects of search can be aided by incidental scene learning. Here I focus on the incidental learning of what distractors might look like and how possible target locations can become prioritized in scenes, both of which offer advantages in making search efficient.

An important factor in the search of both arrays and scenes for targets is the degree to which distractors are processed. If the same distractors are seen repeatedly and rejected as non-targets (such as in Gibson et al., 2000), then participants may learn something of what identifies distractors, as they must for targets. Hout and Goldinger (2012) established that the incidental learning of distractors reduces the number of fixations needed to first fixate targets but not the verification time associated with identifying targets. Therefore, the more familiar an individual is with the distractors contributing to an array or a scene, the less time will be required to search, which occurs with no additional cost to accuracy (Hout & Goldinger, 2012).

The incidental learning of distractors is most striking for distractors that are similar to the targets being sought. First, the later recognition for distractors is highest when they are semantically related to the targets (Williams, Henderson & Zacks, 2005). Second, when multiple targets are being sought, each distractor must be considered as potentially being part of either one or many categories (Hout & Goldinger, 2010). The general principle here is that distractors that are harder to reject, by virtue of extended processing of them over time, become learnt. The result of this learning is that we become better at rejecting these distractors as our experience with them increases.

Incidental learning can also result in the prioritization of locations to search. Chun and Jiang (1998) argued that the majority of targets appear in the context of other objects that combine to form an overall global scene/context. Chun and Jiang proposed that the instance-based nature of implicit learning allowed interaction between explicit episodic memory traces (i.e. “the last time I was here, I saw this”) and attentional mechanisms to guide search when the memory of the scene is implicit. In order to test this hypothesis Chun and Jiang (1998) ran a series of experiments that presented a display of distractors and targets (T and L characters on a uniform background). Participants were shown some trials where subsets of distractors appeared repeatedly across trials in the same configuration. Target detection was faster when both targets and distractors appeared in these repeating configurations than when in novel configurations. The magnitude of this difference increased with the number of repetitions shown to participants, despite participants being unaware of it. The same result was found when the background set of distractor items changed in appearance, but not location, halfway through the session, indicating it is the repeating configuration that is important (Chun & Jiang, 1998).

The benefits of contextual cuing occur with previously unfamiliar objects (Chun & Jiang, 1999) are increased by adding colour to some distractors (Jiang & Leung, 2005), are still evident up to a week following the initial exposure (Chun & Jiang 2003), and are robust to repetition occurring within small (e.g. 60) and large (e.g. 1800) stimulus sets (Jiang, Song & Rigas, 2005). There is some suggestion that the location of repeating distractors is important, with a greater context effect being found when repeating distractors were close to the target (Olson & Chun, 2002).

The studies by Chun, Jiang and colleagues all use basic feature and conjunction stimuli and not real-world scenes. Other studies have shown that the effects of contextual cuing are prominent when real-world scenes are used. Brockmole and Henderson (2006a) reported reductions in RTs of up to 2 seconds in repeated arrays following only 4 repetitions of the scene. This is a larger effect than in the original contextual cuing tasks where benefits of 60-80ms were found after 15 repetitions of the spatial arrays (Chun & Jiang, 1998; Brockmole & Henderson, 2006a). Additionally, participants were much more likely to correctly identify the repeated scenes following the task, indicating an explicit awareness that is not demonstrated with repeated arrays. In order to test whether it was the recognizable nature of these scenes that was driving the effect, the authors re-ran the experiment with scenes inverted. While contextual cuing did appear in the inverted scenes, it took significantly longer to manifest to the same degree of benefit as the original scenes (Brockmole & Henderson, 2006a). Brockmole and Henderson concluded that contextual cuing occurs earlier if the scenes are more relatable to the viewer (i.e. in the correct orientation).

Interestingly, when the various colour levels of the scene were manipulated so as to make them appear unnatural, the contextual cuing effect did not change (even when the unnatural colour pattern was only changed in the final block, Erhinger & Brockmole, 2008). This would suggest that while inverting real-world scenes is enough to delay the contextual cuing effect, this does not apply when the scenes change colour.

Two further findings are of interest. First, when learned real-world scenes with consistently placed targets were mirror-reversed along the vertical axis, the effect of learning was still preserved (Brockmole & Henderson, 2006b). However, in the initial transfer block the direction of eye-movements indicated a tendency, upon recognizing the scene identity, to move towards the older location of that target in the non-reversed state (Brockmole & Henderson, 2006b). Second, contextual cuing has also been reported when previous examples predict location, even when the new scenes have never been shown before (i.e. cued by a local element through experience, such as finding a target is always located on a pillow in a series of photographs, Brockmole & Vo, 2010).

In summary, I have shown that the implicit learning of the global context set by targets and distractors demonstrated in the various studies outlined above is important in illustrating a mechanism to support contextual learning of scenes. This mechanism must be understood in relation to the implicit mechanisms that help encode target and distractor identities. Together, they show how increasing familiarity with targets, distractors and scenes can improve the visual search for targets. When real scenes are used, the same fundamental effects are found but participants can become explicitly aware of their learning. This mix of implicit and explicit learning of the regularities that underpin target, distractor and context learning are important in explaining how top-down influences improve search.

As outlined above, the present thesis sets out to explore if being able to predict forthcoming scenes that are spatio-temporally linked to the present scene can improve search. Critically, those conditions are precisely what we experience when searching for targets when moving through the world. The question is justified by the extrapolation from searching in the real-world for the purpose of detecting possible threats. However, it presupposes that we have both a memory for scenes themselves and for the order of scenes, and that this might support searching. Existing evidence is consistent with this supposition. Studies have shown that participants are able to correctly recognize hundreds of scenes with only a limited amount of exposure to each stimulus (Standing, 1973; Shepard, 1967). Moreover, previewing a scene is known to influence how it is searched when a target appears. Hollingworth (2003, 2006) described a task in which realistic computer-generated scenes were searched for targets, either with or without a preview of the scene for several seconds. A distinct advantage occurred in the preview condition, even if the search target was altered in orientation between the preview scene and the search trial. The benefits of the preview screen were seen in both RTs and in the time taken to first fixate the target, with detection made within 1 or 2 fixations. Previewing a scene also allowed participants to report where certain targets were likely to be. There is, therefore, reason to believe that the fundamental mechanisms of scene memory are in place and are able to help target detection in forthcoming scenes.

Two areas of the literature will be reviewed further, in order to answer the questions of both how the prediction of forthcoming scenes can aid search, and to what extent this ability can be enhanced or disrupted.

There are two clear reasons why a greater understanding of the research question is necessary and to what extent can this learning be modulated. The first is in order to understand how we search for targets in the real world. Aside from the issues presented above, the extent to which knowledge about the environment is learned by individuals completing routes may be facilitated by mechanisms that influence the way in which attention is directed and targets processed while completing search, such as the attentional or working memory networks.

The second reason for engaging with the question lies in the real-world consequences of search. In many real-world tasks the risks associated with being fast or slow to find a target are minimal, however, there are occasions where quick detection and correct decisions are critically important for maintaining safety and personal wellbeing. One example of such a task is the search for improvised explosive devices (IEDs) that might be hidden, camouflaged, or even buried in the ground. The regularities that exist in the placement of IEDs make some places and locations more likely to hold targets than others (Mostak & Stancl, 2006). The search for IEDs hidden in such situations may potentially happen when an individual is in an understandably heightened state of anxiety or worry, which may increase the likelihood of injury, due to the increased chance of cognitive errors being made while anxious (Garner, Attwood, Baldwin, & Munafò, 2012).

It should also be considered that the degree to which the factors I have mentioned may affect search may vary considerably across individuals, as the difference between individuals in faculties of working memory, attentional networks and predisposition towards anxiety, depression or cognitive failures is highly variant. Therefore, some consideration will be made of these factors and their influence on search and learning processes.

In the final two sections of the Introduction I provide some background to the study of individual differences in relation to attention, working memory, anxiety and depression with respect to how they might influence target search efficiency by modulating search processes.

1.3 Attention, working memory and prediction of forthcoming scenes

The ability to use contextual information to predict target location in forthcoming scenes must build on the implicit and explicit learning of targets, distractors and scenes, as described above. Fundamental to this ability are attention and working memory processes. In this section, I describe both how these processes might enable efficient target detection, and how they may facilitate the use of the current scene to predict the upcoming environment.

1.3.1 Attention

Attention is most simply defined as the selection or control of information for processing, usually of relevant signals out of a consistent stream of noise (information not relevant to the particular task that is being undertaken). In the context of this thesis, attention refers to the selection of information from the visual field, and the ability to engage and shift attention, to focus on task goals and to remain alert may all be important in allowing participants to prepare for the likelihood of target presence in upcoming scenes. Posner and Petersen (1990) proposed a system of anatomical areas that support three independent attention-based systems: the alerting, orienting and executive control networks (see also Petersen & Posner, 2012). The way in which these networks operate to help participants complete search and prepare for upcoming scenes will be discussed below.

The alerting network underlies the ability to respond to sudden onset stimuli, without expectation or preparation (Fan, McCandliss, Sommer, Raz, & Posner, 2002; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Posner & Petersen, 1990). Within the context of search during a real-world task (e.g., driving a car), the alerting network may signal the sudden appearance of a target in the visual field (e.g., turning a corner and seeing a red traffic light up ahead).

In terms of using the current scene to predict the future environment, the alerting network may respond when a suddenly appearing target indicates a specific type of upcoming event (e.g., a warning light at a railroad crossing), thus warning of a danger further ahead. Knowledge of the environment ahead (i.e. in this example, that railway lines are used by trains) allows the driver to stop the car.

To the example of overt alerting signals such as the red light at the railroad crossing, there is a possibility that the environment itself might act as an alerting cue. It has been noted above that repetition leads to the encoding of contextual information that can speed target detection. If there is a change in what is expected in the visual field prior to being presented in that particular scene (for example, a new pedestrian crossing) then the change in the expected spatial outline in the visual field may also cue the attention of participants. In addition, if a particular unseen location contains mobile or shifting targets, then an individual may prime their search responses to attend to particular signals suddenly appearing or changing in luminance, which is afforded by the foreknowledge of the environment based on earlier searches.

Aside from the alerting network, the orienting network also plays an important part in visual search. Attentional orienting is the ability to direct attention within a given environment based on bottom-up or top-down cues to specific locations (Fan et al., 2002). I noted above that bottom-up cues are defined by changes in the value of stimulus feature. In contrast, top-down cues are symbolic (e.g. arrows) or rely on task knowledge. By definition, preparing to orient to a visual scene that has yet to be seen cannot rely on bottom-up cues but must rely on the use of this top-down knowledge (e.g. the spatial outline of the environment to appear). It seems plausible that the orienting prior to the onset of a scene might be possible *if* participants were confident that a target appearing in an immediately forthcoming scene would, if present, only appear in one or several specific locations. Surprisingly, the literature on contextual cueing provides no data that addresses this question, however data on this issue is provided in the present thesis.

The executive-control network refers to the ability to direct attention to the correct stimuli and ignore irrelevant or disruptive signals and as such maintain task focus. For example, while monitoring the conflicting signals of red and green lights at a controlled roundabout, stronger executive control is shown when the driver only responds to the signals that are relevant for their lane. Importantly, the executive control network can influence the other two attentional networks by moderating the breadth of signals to be monitored (e.g. Fan et al., 2002). Searchers must, after all, define the limits of what is to be searched. For example, while the familiar environment may have changed recently (e.g., new shops along a high street), that does not necessarily mean that attention should be given to that part of the visual field when concentrating on the central task of driving. Likewise, knowledge of the environment as it appears should only allow for attention to be allocated to signals that are of explicit use to the driver. An individual with poor executive control might be inclined to direct their attention to areas of the visual field which are not useful for the current task.

In summary, the three attention networks outlined above may each influence how attention is allocated to the forthcoming environment, based on the context offered by the current one. The three networks associated with supporting attention (alerting, orienting and executive control) have been shown to be independent of each other (though see MacLeod et al., 2010), and can all be reliably tested using a single task: the Attentional Network Test (the ANT; Fan et al, 2002). This task involves attending to a central cross on a screen and observing an array of arrows appearing either above or below the cross. Participants are instructed to respond to the direction of the central arrow (either left or right), with the arrows on either side acting as distractors. Utilising a series of cues, and whether or not the distractor arrows pointed in the same or different direction as the central target (see Chapter 2 for further details), assessments of the alerting, orienting and executive control networks can be made, and have been used in a great number of studies (see MacLeod et al., 2010 for review). Participants are tested on the ANT throughout the experiments presented in the current thesis, to gain further insight into the role of attention in the ability to use current contextual information to facilitate the detection of targets that *might* be about to appear.

1.3.2 Working memory

Working memory (WM) can be described as the ability to retain and manipulate small amounts of information for a relatively brief period of time in order to support many complex cognitive tasks (see Shah & Miyake, 1999 for a review). According to Baddeley (1983; 2000), WM has at least four distinct components that subserve separate cognitive functions: the central executive (an attentional control system), two “slave” subsystems of the phonological loop (allowing verbal/auditory rehearsal) and the visuospatial sketchpad (allowing the retention of visual information, even across eye-movements), and the episodic buffer (which binds information from both the phonological loop, the visuospatial sketchpad, and long term memory). WM is crucial to our abilities of knowledge acquisition and skill learning (Alloway, Gathercole & Pickering, 2006) and problem solving (Unsworth & Engle, 2005; Engle, Tuholski, Laughin & Conway, 1999; see Simons et al., 2016 for review).

Researchers have investigated the role of individual WM components in search tasks. When the phonological loop (i.e. verbal WM) is filled to capacity (through the maintenance of unrelated objects for later recall), then there is no detrimental effect on the accuracy of search (Woodman, Vogel & Luck, 2001). However, when the visuospatial sketchpad is filled (via a visuospatial WM task), both performance on the WM task (Oh & Kim, 2004) and search task suffer (longer RTs; Woodman & Luck, 2004). These studies support the view that separate components of WM affect search processes in different ways, with particular emphasis on visuospatial WM. It should be considered that the lack of impact of filling the phonological loop with unrelated information to the search task had no impact upon search precisely because the maintenance did not require the interaction of other WM processes. When, for example, the information stored in verbal WM required manipulation rather than maintenance, there was a detrimental effect on search performance (Han & Kim, 2004). These findings tie in with the dual-target cost observed in some experiments, in which one of several possible targets appears in the area to be searched (e.g. Godwin, Menneer, Cave & Donnelly, 2010; Stroud, Menneer, Cave & Donnelly, 2012). The maintenance of several search templates would necessitate the use of verbal WM, information which would doubtless interact with other components of WM. The extrapolation of the full outline of, for example, a partially hidden bladed weapon in an x-ray baggage search, would require use of the visuospatial sketchpad, and the maintenance of spatial positioning and the comparison with multiple target identities held in verbal WM will have a dramatic effect on the ability to search quickly and accurately.

WM is therefore implicated in searching for targets in more than one way. First, WM is where visual representations of target templates are held (Desimone & Duncan, 1995) and, according to some theoretical perspectives, where matching of stored templates to incoming visual input occurs (Bundesen, 1990). Restrictions on the number of items that can be simultaneously matched against items in WM are typically thought of as a major factor in the inefficiency of searching for all but the simplest of targets (Treisman & Gelade, 1980; Quinlan 2003; Wolfe, 1994 & 2007; Wolfe, Cave & Franzel, 1989; Sobel, Gerrie, Poole & Kane, 2007). There are, therefore, profound limitations on the number of targets that can be stored in WM. Searching for multiple targets ultimately must increase the WM load, which results in both increased search times (as distractors and targets required comparison against multiple categories rather than one), with a side benefit of improved recall for distractor identities (Hout & Goldinger, 2010), particularly when those distractors are semantically close to the target identities (Williams, Henderson & Zacks, 2005).

WM may be implicated in searching for targets in at least one other way. If contextual cuing can influence the efficiency of target detection when presented with a scene, then it may be that it can also serve as a cue to forthcoming targets. In other words, recognition of a particular scene may tell us that there will be a target in a particular location of the following, and as yet not-visible, scene. If so, and given that such cuing cannot be directly related to visual input (as this contextual benefit would constitute a top-down knowledge driven influence, rather than bottom-up visual input), such a process would rely on WM. If so then prediction might be related to the capacity to mentally project oneself forwards, with reference to the spatial layout of the following scene. It might, on the other hand, be related to the ability to verbally encode scenes and their spatio-temporal relationship to forthcoming scenes. The likelihood of this might be raised in circumstances where the contingency linking targets to scenes and locations are such that participants come to learn that, for example, that a target always follows presentation of a specific scene.

In summary, there is reason to hypothesize that visuospatial and verbal WM capacity may play a role in using the present context to enhance the efficiency of searching for targets in forthcoming scenes. In order to test this hypothesis, participants in the experiments presented in the present thesis will also have their visuospatial and verbal WM capacity measured.

1.4 Individual differences in visual search of upcoming scenes

The central research question of this thesis concerns how the present context might influence search of forthcoming scenes for targets, as participants become more familiar with scenes through repeated presentations. I have identified contextual top-down influences on the learning of targets, distractors and scenes, along with the use of attention and WM networks to enable efficient allocation of attention on the basis of visual problem solving. Visual problem solving can occur through extrapolating from the current to forthcoming scenes. Individuals' differences may influence each of these components that might underpin increased search efficiency for targets in forthcoming scenes that can be predicted. This section considers the potential influence of depression, cognitive failures and anxiety in reducing any search efficiency gain that might come with being able to predict forthcoming scenes. While depression and cognitive failures and anxiety may not form an exhaustive list of potential influences[1], they are particularly important in the context of applying the work of the present thesis to the issue of searching for IEDs and other threats in unsafe conflict zones.

1.4.1 Depression and cognitive failures

Estimates of the frequency of depression or depressive symptoms suggest it is experienced by over one in ten in the general population (McManus, Bebbington, Jenkins & Brugha, 2016). Depression has a multitude of effects on cognition generally (e.g. Rabbitt, Donlan, Watson, McInnes, & Bent, 1995; Kizilbash, Vanderploeg & Curtiss, 2002), and while depression is unlikely to influence basic visual processing, it is implicated in attention (Hammar, Lund & Hugdahl, 2003a, b), WM (Weiland-Fiedler, et al., 2004) and learning (i.e. Basso & Bornstein, 1999; Fossati et al., 2004; Stordal et al., 2004). The overall effect is that depression can increase the effort required for attentional processes, make learning maladptive, and increase focus on negative stimuli (Joormann & Gotlib, 2007).

Depression and depressive symptoms do not necessarily occur in isolation and can be associated with cognitive failures (Sullivan & Payne, 2007). Cognitive failures can be broadly described as lapses in decision making, and have been shown to increase the probability of careless errors and workplace accidents (Wallace & Vodanovich, 2003; Larson, Alderton, Neideffer & Underhill, 1997), as well as driving accidents (Lasron & Merrit, 1991).

In summary, it is likely that in the context of search, depression and cognitive failures may compromise the ability to learn from the current environment (for later searches) through reduced learning, increased attentional effort and

[1] For example, impulsivity (Anderson & Revelle, 1983) and age (Ball, Beard, Roenker, Miller & Griggs, 1988) have been shown to influence search. Additionally, individuals with autism-spectrum disorder have shown enhanced search processes (via improved RTs; Joseph, Keehn, Connolly, Wolfe & Horowitz, 2009; Plaisted, Riordan & Baron-Cohen, 1998).

impoverished decision-making. This may apply to searching the current scene and when planning search in forthcoming scenes. It is therefore highly probable that propensity towards depression and cognitive failures may impact learning. For these reasons, I measure participant scores on indices of depression and cognitive failure to allow exploration of how these factors might influence search and its efficiency.

1.4.2 Anxiety

Anxiety is an emotional state in which a person is sensitive to worries, tensions or to potential threats (Eysenck, Payne & Derakshan, 2005). Individuals can either be susceptible to anxiety as a factor of their personality (trait anxiety, which has been estimated to affect over a third of the population during the course of their lives; Bandelow & Michaelis, 2015), or as a result of their current circumstances (state anxiety, Derakshan, Smyth & Eysenck, 2009).

In laboratory studies using schematic or simplified stimuli, anxiety is known to be important in visual search for some classes of threat target (Matsumoto, 2010). Furthermore, when an individual suffers from a particular phobia, they may have improved search times for stimuli that trigger the phobic response (such as spiders or snakes; Flykt & Caldara, 2006; Soares, Esteves, Lundqvist, & Öhman, 2009; see Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg & van IJzendoorn, 2007 for a review). The argument offered is of an evolutionary necessity for anxiety to signal potential danger, allowing some attentional processes to be allocated specifically to threatening targets (Byrne & Eysenck, 1995; Bar-Haim et al., 2007). In related studies, where threats are distractors rather than targets, anxiety is associated with increased distractibility (Eysenck, Derakshan, Santos & Calvo, 2007; Gerdes, Alpers & Pauli, 2008; Derakshan, Ansari, Hansard, Shoker and Eysenck, 2009).

There is an interesting question in relation to the relevance of this work to the present thesis. Clearly, the gap between laboratory studies using simplified stimuli and the scenarios of searching dangerous environments (for example, IEDs in conflict zones) is wide. The targets in the literature reported above represent evolutionary threats, and the question of the influence of anxiety on search in real-world scenes for *human-made* threats remains largely unexplored.

In contrast, the evidence for the influence of anxiety on the basic processes of attention and WM that support search, and, I have argued, the ability of these processes to enable the use of context to help the search for forthcoming targets, seems robust. Studies using the ANT (Fan et al., 2005; 2002; Posner & Petersen, 1990), where participants performed the task while breathing an increased level of CO_2, have shown reduced cue alerting and validity effects. These data show the orienting and alerting networks are affected by both state and trait anxiety and their interaction (Garner, Attwood, Baldwin, & Munafò, 2012). Increased anxiety also affects the executive control network such that anxiety is associated with increased distractibility (Pacheco-Unguetti, Acosta, Marqués & Lupiáñez, 2011). The influence of anxiety on attention has been conceptualised in terms of Attentional Control Theory (ACT, Eysenck et al., 2007) such that high levels of anxiety lead to reduced attentional control (Eysenck et al., 2007).

With respect to the influence of anxiety on WM, the evidence suggests anxiety influences the efficiency with which WM is used. Here I refer to efficiency in terms of task demands and the cognitive resources used to achieve them (Processing efficiency theory: Eysenck & Calvo, 1992). Participants with increased levels of state anxiety have slowed responses in a verbal WM task (Hou et al., 2015), whereas those with higher levels of trait anxiety take longer to complete grammatical reasoning tasks while maintaining a series of digits (verbal WM, although task accuracy is not affected, MacLeod & Donnellan, 1993). Participants completing the Corsi block task (a visuospatial WM task), while simultaneously counting backwards to fill the central executive, were more likely to exhibit poor performance if they reported high levels of trait anxiety (Eysenck, Payne & Derakshan, 2005). With respect to the central executive, increasing state anxiety through the threat of a minor electric shock reduces performance on visuospatial but not verbal versions of the n-back task (Shackman et al., 2006; Lavric, Rippon & Gray, 2003).

As state and trait anxiety affect attention and WM, the following experiments measure participant scores on indices of state and trait anxiety, as well as on WM, to allow exploration of how these factors might influence search and its efficiency.

1.5 Direction for the Present Thesis

The introduction above has outlined the central question that forms the foundation of this thesis: how does the ability to predict forthcoming scenes affect search processing within them?

In typical everyday experience, the world around us appears relatively static, and our environment is unlikely to change dramatically from moment to moment. This relative constancy allows us to build contextual knowledge, which in turns drives much of the allocation of attention during search. A vast, detailed literature has explored the joint influence from the visual field (bottom-up influences) and from knowledge of the target and scenes (top-down influences). Throughout the literature the use of eye movements alongside behavioural measures has allowed the cognitive processes supporting search to be further scrutinised. What is not known, however, is how the knowledge of the environment, which is based on previous experiences, benefits search upon the return to that environment. The central theme of this thesis, in other words, is how does knowing the spatial outline of an upcoming environment, or potential target locations, influence the preparation for and eventual search of that environment when it comes into view? This question is of academic interest to those who investigate the dynamics of search behaviour in humans. It also becomes of paramount importance when considering the behaviour of individuals who may be searching dangerous environments (e.g. in conflict zones) for multiple target categories and with a large number of probable targets. Particularly, for those searching for IEDs, the ability to use the knowledge of an environment to inform efficient search can be potentially life-saving.

This review has established that the ways in which we search both novel and repeated environments may depend on cognitive faculties that vary greatly between individuals. Both search and memory processes can be influenced by WM faculties, and the deployment of attention through the visual field is facilitated by the functioning of attentional networks. The degree to which search through repeated scenes that form routes is both effective and efficient may depend on the relative strength of these cognitive faculties. In addition to this, search efficiency through repeated scenes and routes may be hindered by either weakness in these cognitive capabilities or by psychological influences, such as anxiety, cognitive failures or depression. These have been shown to influence both the deployment of the attention and WM, and search processes themselves. When considering those who commit searches in dangerous environments, the question of how these cognitive or personality factors may lead to either improved or inhibited decision making is of extreme importance.

In the following three chapters, two questions central to critical issues in search will be answered. First, does being able to predict upcoming scenes and targets influence search? Secondly, to what extent do cognitive and psychological factors support or hinder this ability? To address these questions, a novel eye-tracking experimental paradigm was designed that allowed participants to view a route through a suburban area while they completed a search task for targets appearing in naturalistic positions. The experiment design was termed "the repeated scenes search task" (RSST), and either presented real-world routes as a static sequence of images that were searched in a consistent order, or as a randomised string of images, while tracking participants eye movements through the scene.

Chapter 2 presents findings from three experiments that utilised the RSST and manipulated the presence or absence of targets in scenes. The experiment assessed the effect of viewing the scenes either in or out of the consistent order when targets were randomised (Experiment 1), appeared in the same scene (Experiment 2) or appeared in both the same scene and position (Experiment 3). The influence of attentional networks and visuospatial and verbal WM capacity upon learning in search was also investigated across experiments.

Chapter 3 introduced two interventions aimed at enhancing WM: daily WM training for a period of 15 days, or transcranial direct-current stimulation (tDCS). The aim was to establish if boosting WM may have a benefit upon behavioural or eye movement measures recorded during the RSST.

Chapter 4 presents an experiment focused on investigating the impact of a state of anxiety upon search in repeated routes. Participants completed the RSST in two scenarios; once while breathing in normal air, and once while breathing in a gas that contained 7.5% carbon dioxide (CO_2), which has reliably been shown to induce a mild state of anxiety. The impact of anxiety upon behavioural and eye movement measures is discussed, including the influence upon participants' ability to learn from earlier experience.

In Chapter 5, the implications of these empirical findings are discussed both in the context of the existing scientific literature and with relation to those completing searches in hostile environments.

Chapter 2 The influence of learning routes on the visual search for targets

Prepared for publication: Tew, O., Godwin, H. J., Garner, M., Hadwin, J. A., Liversedge., S. P. & Donnelly, N. *The influence of learning routes on the visual search for targets*

2.1 Introduction

Visual search (hereafter termed search) for targets is faster and more accurate when targets are presented in familiar than unfamiliar contexts (Frith, 1974; Reicher, Snyder & Richards, 1976; Henderson, Malcolm & Schandl, 2009), when targets are repeatedly presented in the same relative to varying locations (Brockmole & Henderson, 2006a, b, Chun & Jiang, 1998 & 1999; Olson & Chun, 2002; Jiang, Song & Rigas, 2005), when scenes are structured rather than unstructured (Biederman, Glass & Stacy, 1973), when targets are constrained to naturalistic locations within the scene (Neider & Zelinsky, 2006) and when distractor identity and position remain constant over trials (Hout & Goldinger, 2010, 2012).

In the present study we explore if being able to predict forthcoming scenes enhances (i.e. speeds and makes more accurate) search for targets. There is some previous literature that explores the role that previewing scenes might play in speeding search (e.g. Hollingworth, 2003, 2006). In these studies, the preview and search scenes are identical other than with the inclusion of targets. Here we consider if search for targets can be improved by being able to predict forthcoming scenes by virtue of their location in the real world. We ask this question while varying the contingencies that link targets to scenes across three experiments. While it might seem obvious that prior knowledge of forthcoming scenes should enhance the search for targets, there is at least one reason why it might not. Studies of scene categorisation have shown that at least some aspects of scene processing are supremely efficient (Thorpe, Fize & Marlot, 1996; VanRullen & Thorpe, 2001, Castelhano & Henderson, 2008). It might be, therefore, that the efficiency of scene processing overwhelms any advantage that prior knowledge of forthcoming scenes might offer.

In the present study, participants searched for targets embedded in photographs taken at short intervals along a route. The route showed a path through a suburban neighbourhood. The sense of a route in the photographs was reinforced in two ways during the experiment. First, decisions about target presence for one scene were followed by the presentation of a highlighted cue showing the visible area of the next scene on the current scene (see Figure 1). Second, participants were shown the same set of images in this order eight times to reinforce the spatial and temporal relationship between images.

The aim of the study was to determine if and how the efficiency of search changes with growing familiarity with the scenes. Common to standard search tasks, the time and accuracy of target detection was measured. The main prediction was that being able to predict forthcoming scenes would lead to faster and more accurate search for targets.

Eye movements were also recorded as participants searched for targets. Eye movements made during search are influenced by multiple factors. Locations fixated are influenced by semantic knowledge of environments (Neider & Zelinsky, 2006), scene familiarity (Hollingworth, 2003) and certainty of target identity (Yang & Zelinsky, 2009). In addition, control of fixation directions (Shank & Haywood, 1987), durations (Van Gog, Paas, Merriënboer, 2005) and target dwell times (Law et al., 2004) are influenced by task expertise and target prevalence (Godwin, Menneer, Cave, Thaibsyah & Donnelly, 2015).

Evidence of an effect of being able to predict forthcoming scenes on the search for targets might be underpinned by enhanced search and/or decision-making. Enhanced search might be evidenced by reduced time before fixating targets. Enhanced decision-making might be evidenced by shorter fixation durations and target verification times. Enhanced search and decision-making would exhibit both reduced fixations and shorter fixation durations and target verification times, and an increased functional field of view. An increased functional field of view would be evidenced by an ability to accurately respond 'target-present' without making fixations directly on targets (e.g. Li, VanRullen, Koch, & Perona, 2002; Thorpe, Gegenfurtner, Fabre-Thorpe, & Bülthoff, 2001).

Finally, the ability to use forthcoming scenes to enhance the search for targets may be an attribute of skilled performance exhibited by some but not others. The ability to utilize forthcoming scenes to aid search for targets would, a priori, seem to depend on at least two core cognitive skills. First, the ability to predict onset of one image from another may be aided by the quality of representations held in long-term memory and its recall into working memory (WM, Houtkamp & Roelfsema, 2006). Second, the guided inspection of scenes or decision-making about targets may require the control of goal-focused attentional processes to alert and orient attention to locations within scenes (Fan, McCandliss, Sommer, Raz & Posner, 2002). In the present study, we took measures of verbal and visuospatial WM strength and three separate attentional networks (alerting, orienting and executive control, Fan et al., 2002). We did so to seek evidence that individual differences in WM and visual attention might support the ability to use knowledge of forthcoming scenes to enhance the search for targets. The experimental method for presenting scenes depicting a route either in the consistent or randomized sequences while completing a search task has been termed the repeated scenes search task (RSST).

2.2 Repeated Scenes Search Task (RSST) Experiment 1: Detecting targets in randomised and ordered sequences of scenes

2.2.1 Introduction

We hypothesized that the repeated presentation of ordered sequence of scenes in the RSST would lead to faster and more accurate search for targets relative to when scenes were randomised. Furthermore, we predicted that the increased efficiency of search for targets occurring in ordered versus randomised scenes would be reflected in systematic changes in eye movement behaviour. Consideration of individual differences (measures taken by the n-back task and the attentional network test [ANT]) in the ability to use forthcoming scenes to enhance the efficiency of search is made after reporting of RSST Experiments 1 – 3.

2.2.2 Method

2.2.2.1 Participants

Forty participants (28 Females, aged 18-36, M = 25.17 years, *SD* = 5.24) took part in Experiment 1. All participants were undergraduate or postgraduate students at the University of Southampton. Participants were compensated for their time either with course credits or with small monetary payment at a rate of

£6.00 per hour. All participants had normal visual acuity (a minimum 1.0 decimal VA at a viewing distance of 1m) as measured by the Freiburg Visual Acuity Test (Bach, 1996) and all passed the City University Colour Vision Test (3rd edition; 1998) indicating they had normal colour vision.

2.2.2.2 Apparatus

All stimuli were displayed on a 21-inch CRT monitor (resolution 1024 x 768 pixels, refresh rate of 120Hz). Participants were sat 67.5cm away from the monitor. During the RSST participants used a chin and forehead rest to minimise head movements while eye movements were recorded. Stimuli were presented binocularly but only movements of the right eye were recorded during the RSST. Eye movements were recorded using an SR Research EyeLink 1000 at a sampling rate of 1000Hz. A separate SR Research computer controlled both the camera and the stimuli displayed. The experiment was run using Experiment Builder.

2.2.2.3 Repeated Scenes Search Task (RSST)

The stimuli were constructed from 80 photographs of street scenes taken along two suburban neighbourhood routes (two routes made up of 40 scenes in each). The 40 photographs making up each route were taken so that they formed a spatially and temporally defined sequence and so that the contents and perspective of the current scene (the spatial arrangement of buildings, trees, etc.) was visible from the preceding scene, though from a more distant perspective (see Figure 1 below). Participants completed sets of 40 images in 8 repetitions (across 8 block); one set in the order in which the photographs were taken (consistent sequence) and one in a random order (randomised sequence). Following a participant response to a scene in the consistent sequence condition, a yellow rectangular cue for the following scene was presented. The cue was presented for one second and highlighted the area of the current scene that would be visible in the following scene (see Figure 1). In the randomised sequence condition, responses led to the re-presentation of the same scene minus the target and no yellow outline, and the randomised order of scene identities changed with each block. In Experiment 1 targets appeared in all scenes on 50% of presentations (4/8).

Targets were hand tools (specifically hammers, pliers, screwdrivers, axes and saws). There were four exemplars of each type of target, resulting in 20 targets used in all experiments. Each of the 40 scenes was presented eight times in total, once in each block. Participants were not shown the targets before the experiment. Targets were embedded in scenes using Adobe Photoshop. Targets were positioned using a virtual 5x12 grid that was overlaid on the bottom two thirds of each scene. Each grid was assigned a number between 1 and 60 with target positions assigned using a random number generator. Only one target could appear in each scene and targets appeared in 50% of scenes. One set of eight repetitions had scenes shown in the consistent sequence (Figure 1) and in the other the order was randomised. Both the sequence orders and routes were counterbalanced across participants

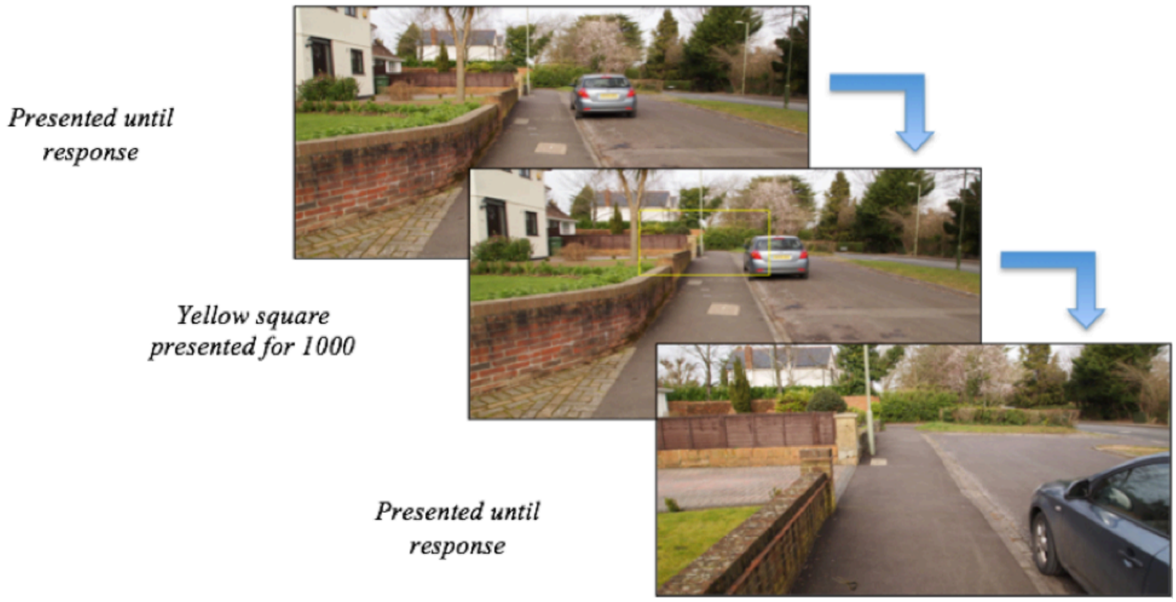

Figure 1. Demonstration of scene progression

2.2.2.4 Individual Difference Measures

2.2.2.4.1 The n-back task

Participants completed two 3-step n-back tasks, one assessing visuospatial WM and the other verbal WM (see Shackman et al., 2006). The n-back task presented a series of letter identities (for 500 ms) within several positions within a square (2500 ms between presentations) and participants judged whether either the letter (verbal condition) or the location within the square (visuospatial condition) was matched with the letter or position from 3 trials previously. The order of whether participants completed the visuospatial or verbal condition first was counterbalanced between participants.

2.2.2.4.2 The attentional network test (ANT)

In the ANT participants are required to gaze at a central fixation point in the centre of the screen. Five arrows appear above or below the fixation point.

Participants were asked to identify whether the middle (3rd) arrow pointed left or right (see Figure 2). The arrows on either side of the target (distractors) either pointed in the same direction as the arrow (congruent distractors) or in the opposite direction (incongruent distractors), and were presented until response. The target location could have been cued prior to each trial by a brief presentation (100 ms) of asterisks (*****). The time to respond to the target, cued or otherwise, and either flanked by congruent or incongruent distractors, are calculated to produce measures of the orienting, alerting and executive control networks (see Fan et al., 2002). The time to respond to the appropriate target is used to generate measurements with respect to the orienting (RT in the no cued trials minus the cued trials), alerting (no cued trials minus trials with cues appearing in both potential target locations prior to presentation) and executive control (incongruent minus congruent trials) networks.

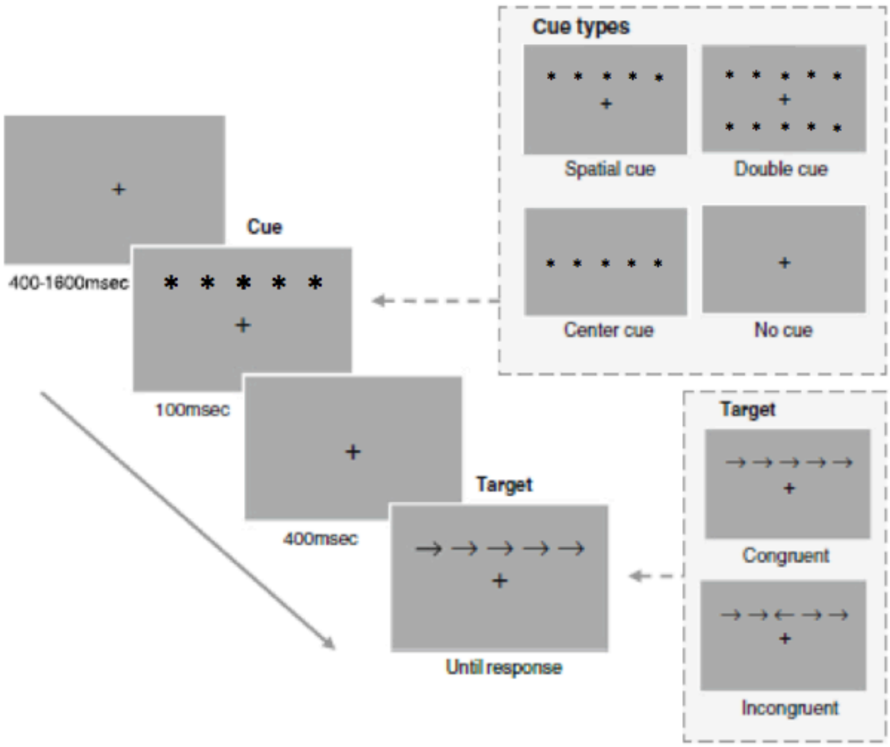

Figure 2. The ANT

2.2.2.5 Procedure

Participants began by taking the visual acuity and the colour vision tests followed by calibration of the eye-tracker. For the calibration procedure, participants fixated a series of 9 dots, which appeared in random order in a 3 x 3 grid. Calibration was deemed successful if all validation measurements were less than half a degree of error. A drift correct was applied before each trial and the eye tracker was recalibrated if necessary.

Participants searched for targets in two sets of eight repetitions/blocks of 40 scenes, making 640 trials in total. Only one target could appear in each scene and targets appeared in 50% of scenes. One set of eight repetitions had scenes shown in the consistent sequence (Figure 1) and in the other the order was randomised. Both the sequence orders and routes were counterbalanced across participants.

Each trial began with a drift correct calibration followed by a gaze-contingent square appearing at a pseudorandom position on screen (the only requirement being that it was at least 150 pixels away from the target). The purpose of using the gaze-contingent square was to ensure that the position of the eye prior to the stimulus appearing on screen was at a minimum distance from the target location within the scene. Once the eye position was over the gaze contingent area, the stimulus appeared and remained on screen until response. Participants were instructed to search the scene until they either found a target or decided there was no target present. Participants were also asked to localise the target prior to response and to complete this task as quickly and as accurately as possible.

Feedback was given via a high pitch major note for correct responses and a low pitch minor note for incorrect responses. Following the response button press, the preview screen (in the consistent sequence condition) or the scene minus the target (random sequence condition) was displayed for one second. Completion of blocks and conditions was self-paced. With short breaks, completing the two routes took approximately one hour 20 minutes.

Following the search task, participants completed a test battery included a 3-stage n-back task (Shackman et al., 2006) and the ANT (Fan et al., 2002)[2].

The experimental procedure was approved by the University of Southampton Ethics and Research Governance Office and the Ministry of Defence

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[2] Participants were also measured on the State-Trait Anxiety Inventory (STAI, Spielberger et al., 1983), the Depression assessment questions in the Hospital Anxiety and Depression Scale (HADS, Zigmond & Snaith, 1983), the Cognitive Failures Questionnaire (CFQ, Broadbent Broadbent, Cooper, FitzGerald & Parkes, 1982) and the Attentional Control Scale (ACS, Derryberry & Reed, 2002). These are not the focus of the present discussion and are not considered further in this study.

Research Ethics Committee (MoDREC), and followed the conventions of the Declaration of Helsinki. Full written consent was obtained from each participant after an explanation of the experimental procedure was provided.

2.2.2.6 Data Analysis

All data were analysed using a repeated measures analysis of variance (ANOVA) with the factors of block (1-8), target (present versus absent) and sequence (consistent versus randomised).

We explored several indices of performance (error rates, reaction times, fixation durations, number of fixations, time to fixate and verify targets, likelihood of responding before fixating target). With the exception of error rates, all analysis was conducted on correct trials only. We predicted that there would be reductions across blocks. In other words, we predicted that both behavioural and eye movements measurements would reflect faster and more accurate search as participants became more familiar with scenes and targets. We also predicted that the learning displayed would be greater in scenes presented in the consistent order.

2.2.3 Results

We began by analysing the behavioural data to determine if predictable forthcoming scenes led to more accurate and faster search. With the exception of error rates, all analysis was conducted on correct trials only. The analyses below all represent repeated-measures ANOVAs across Block (1-8[3]) Target (present or absent) and Sequence (consistent or randomised). If an interaction of sequence and block is reported as significant, we always also conducted the analysis with the data from block 1 removed, which is then reported if the pattern of results is changed. The reason for this is that participants cannot know about forthcoming scenes in block 1 and so any meaningful interaction of Sequence and Block must survive when the data from block 1 are removed. Interactions between Block and Target are explored by comparing the data at block 1 and block 8 between targets type (present and absent), as well as within target types between blocks 1

[3] In other chapters of this thesis (Chapters 3 & 4) the analysis is only run using data from blocks 2-8. The rationale for this is that in Chapter 2 the two of the three experiments had statistical rules that were not contingent on previous experience, i.e. targets appearing in the same location they appeared in this scene the last time it was viewed. As this is a statistical rule present in the version of the RSST used in Chapters 3 & 4, the first block is omitted from analysis.

and 8. Therefore, a Bonferroni adjustment is used (*p* <.0125 [.05/4]). In the instance that there is a significant difference in all four comparisons, then the interaction is assessed by comparing the difference between blocks 1 and 8 between each target type, and therefore conducted on the relative difference in blocks across targets.

2.2.3.1 Behavioural data

2.2.3.1.1 Error rates

The main effects of Block and Target were significant ($F(7, 273) = 2.46$, $p = .019$, $\eta^2_G = .01$; $F(1, 39) = 96.55$ $p < .001$, $\eta^2_G = .24$; see Figure 3). Errors reduced from block one (*M* = 8.25% *SD* = 8.75) to block 8 (*M* = 6.5% *SD* = 8.41) and were also lower on absent (*M* = 2.73%, *SD* = 4.59) than present trials (*M* = 11% *SD* = 9.46). The interaction between Block and Target did not reach significance ($F = 1.69$). Neither the main effect of Sequence nor any interactions involving Sequence reached significance (all *F*s < 0.41)

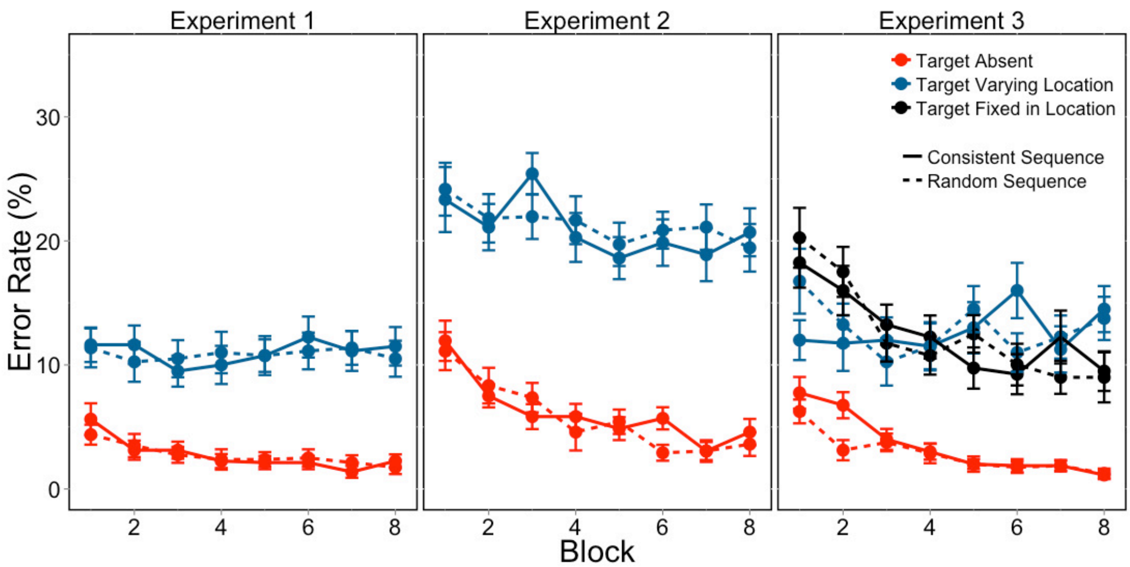

Figure 3. Error rates across Experiments 1- 3

2.2.3.1.2 Reaction times (RTs)

The main effects of Block and Target type were significant ($F\ (7, 273) = 50.10$, $p< .001$, $\eta^2_G = .10$; $F(1, 39) = 127.64$, $p < .001$, $\eta^2_G = .37$; see Figure 4). RTs reduced from block one (*M* = 3408 ms, *SD* = 2714) to block 8 (*M* = 2028, *SD* = 1197) and were faster on present (*M* = 1424 ms, *SD* = 470) than absent trials (*M* =

3346 ms, *SD* = 1865). The interaction between Block and Target type was also significant ($F(7, 273) = 24.71$, $p< .001$, $\eta^2_G = .04$). Target absent RTs were significantly higher than in target present trials at both block 1 (both p < .001) and block 8 (both p < .001). RTs in both target types reduced between blocks 1 and 8 (both $p < .001$). RTs reduced with block more on absent than present trials ($p < .001$). There was no main effect of, or any significant interactions, involving sequence (all *F* ratios < 0.75).

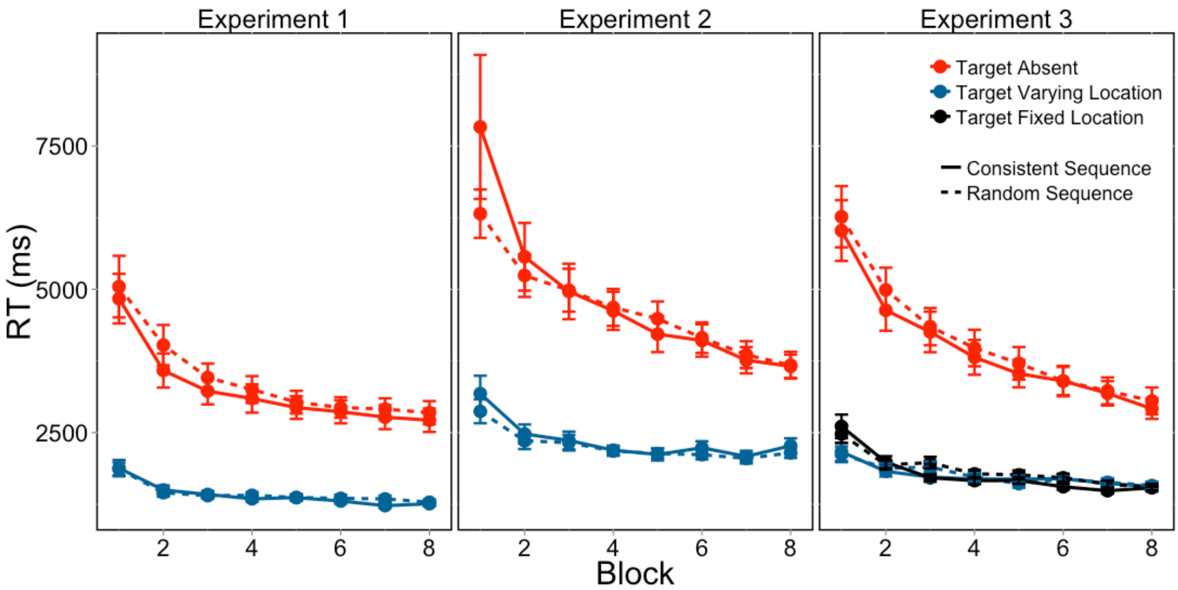

Figure 4. Reaction times across Experiments 1- 3

2.2.3.2 Eye movement measures

We analysed the eye movement data for differences in total number of fixations, mean fixation duration, the time to first fixate targets, verification time, and the likelihood of fixating the target prior to responding. The eye movement data of one of the participants was corrupted and could not be used in the final analysis. Therefore, the data from 39 participants were used in the following analyses. The first fixation in each trial was removed.

2.2.3.2.1 Total number of fixations

The main effects of Block and Target type were significant ($F(7, 266) = 49.01$, $p < .001$, $\eta^2_G = .10$; $F(1, 38) = 144.99$, $p < .001$, $\eta^2_G = .41$; see Figure 5). The number of fixations reduced from block one (*M* = 10.12, *SD* = 9.10) to block 8 (*M* = 5.57, *SD* = 4.02) and more fixations were made on absent (*M* = 10.2, *SD* = 6.12) than present trials (*M* = 3.36, *SD* = 1.38). The interaction between the target type and block was also significant (F(7, 266) = 28.00, p < .001, η^2_G = .05). Fixations in target absent trials were significantly higher than in target present trials at both block 1 (both p < .001) and block 8 (both p < .001). Fixations reduced in both target types between blocks 1 and 8 (both p < .001). Fixations reduced with block more on target absent than present trials (p < .001). There was no main effect, or any interaction, involving sequence (all F ratios < 0.89).

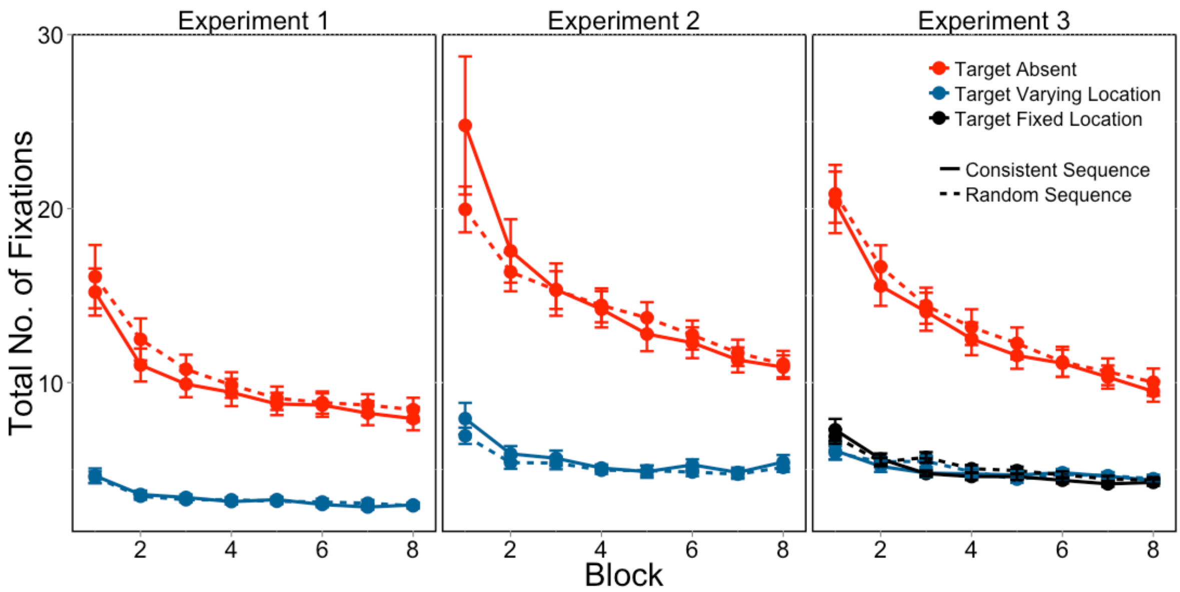

Figure 5. Total number of fixations across Experiments 1- 3

2.2.3.2.2 Mean fixation duration

The main effects of Block and Target were significant (F(7, 266) = 20.01, p < .001, η^2_G = .03; F(1, 38) = 175.3, p < .001, η^2_G = .27; see Figure 6). Fixations reduced from block one (M = 225 ms, SD = 28) to block 8 (M = 212 ms, SD = 29.5) and were longer on absent (M = 225 ms, SD = 23.9) than present trials (M = 204 ms, SD = 27.4). The interaction between Target type and Block was also significant (F(7, 266) = 5.26, p < .001, η^2_G = .01, see Figure 6). Fixation durations in target absent trials were significantly higher than in target present trials at both block 1 (both p < .001) and block 8 (both p < .001). Fixation durations in both target types reduced between blocks 1 and 8 (all p < .001). The difference in fixation duration between block 1 and 8 was significantly greater in target absent trials than in target present trials (p < .002). There was no significant main effect of, or any interaction involving, sequence (all F ratios < 1.89).

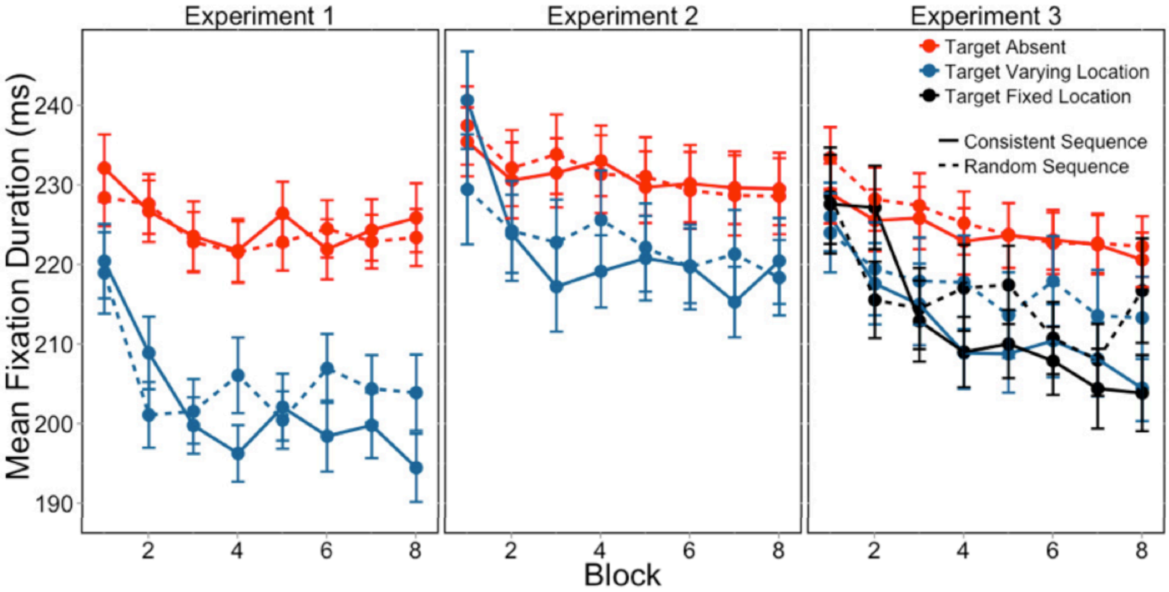

Figure 6. Mean fixation durations across Experiments 1- 3

2.2.3.2.3 Time to fixate target

The main effect of Block was significant (F(7, 266) = 23.12, $p < .001$, η^2_G = .11: see Figure 7), with the time to fixate the target reducing from block one (M = 1115 ms, SD = 603) to block 8 (M = 751 ms, SD = 224). Neither the main effect of sequence nor the interaction between Sequence and Block reached significance (all F ratios < 0.48).

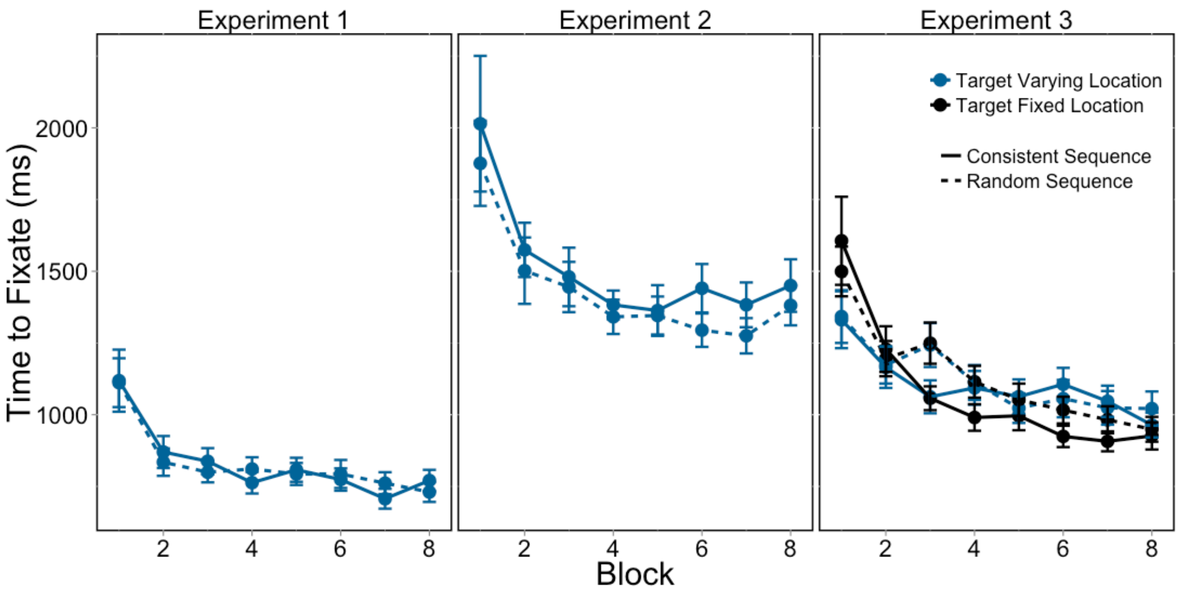

Figure 7. Time to fixate target across Experiments 1- 3

2.2.3.2.4 Verification times

The main effect of Block was significant ($F(7, 266) = 33.04$, $p < .001$, $\eta^2_G = .13$; see Figure 8). Verification times reduced from block one ($M = 783$ ms, $SD = 274$) to block 8 ($M = 571$ ms, $SD = 119$). Neither the main effect of Sequence nor the interaction between Block and Sequence reached significance (all F ratios < 0.45).

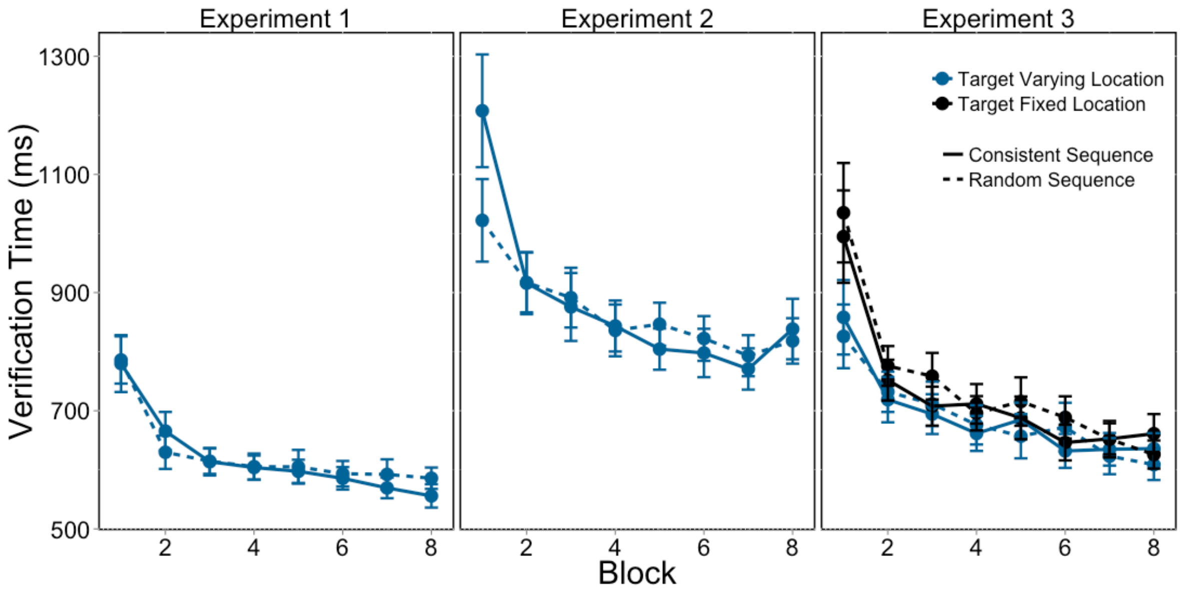

Figure 8. Verification times across Experiments 1- 3

2.2.3.2.5 Likelihood of fixating the target prior to correct response

The main effect of Block was significant ($F(7, 266) = 2.85$, $p = .007$, $\eta^2_G = .025$; see Figure 9). The likelihood of fixating the target prior to response decreased from block one ($M = 92\%$, $SD = 7.24$) to block 8 ($M = 87\%$, $SD = 10.5$). Neither the main effect of Sequence nor the interaction between Block and Sequence reached significance (all F ratios < 1.06).

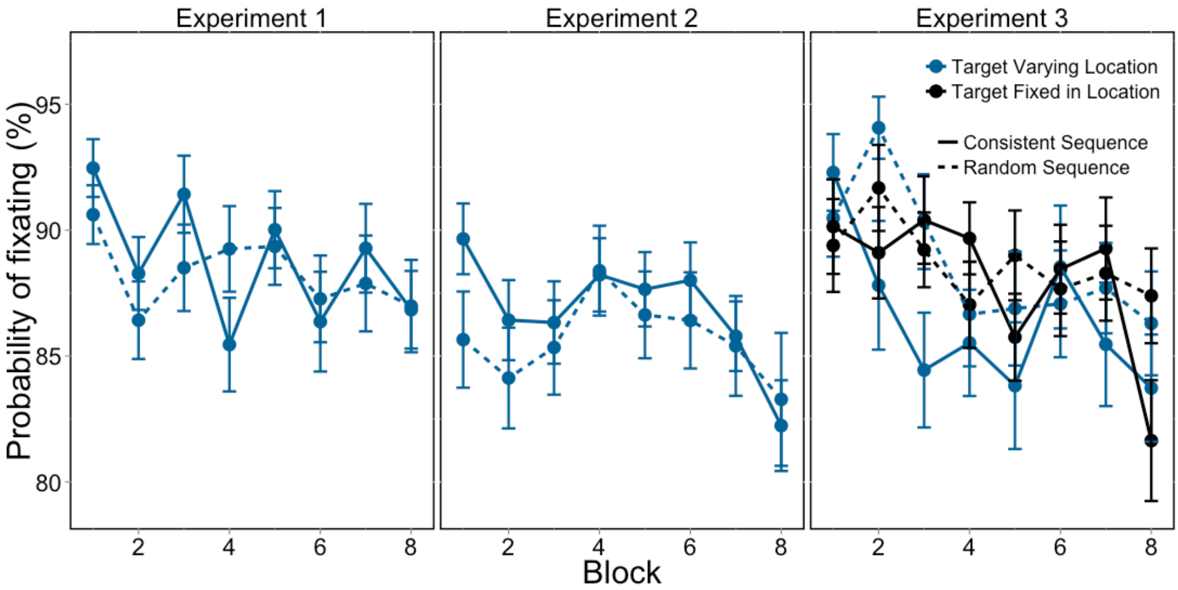

Figure 9. Likelihood of fixating target across Experiments 1- 3

2.2.4 Discussion

In Experiment 1 participants searched for targets in scenes presented in a spatial and temporal order as if walking along a route, or in a randomised sequence. The critical prediction was that having knowledge of forthcoming scenes would lead to faster and more accurate search for targets, and that enhanced search would be reflected in systematic patterns in the eye movement record. We also expected to find the standard differences typically found in search experiments between present and absent trials in terms of behavioural and eye movement data.

The results showed that while search for targets did become more efficient over blocks, and the standard difference between absent and present responses were found, sequence had no effect on any behavioural or eye movement measure. The eye movement data show that the increased efficiency of search for targets was underpinned by reductions in the number of fixations made, fixation durations, verification times, the time to first fixate targets and an increased likelihood of responding without directly fixating targets. This profile of results suggests that the increasing efficiency of search for targets seems to reflect improved guidance and decision-making with time on task, allied to an increase in the functional field of view.

There are two possible reasons for the failure to find an effect of sequence order on search. First, it could be that knowledge of forthcoming scenes might enhance search for targets only if there is a contingency between scenes and target presence (e.g. places where targets are more likely to appear). Perhaps we only learn contingencies to scenes if the scenes themselves allow some prediction in relation to target presence. Contingencies between scenes and target presence might be expressed in a number of ways. For example, targets might be fixed to scenes, or locations within scenes. Experiment 1 tested only the proposition that being able to predict forthcoming scenes would improve the overall efficiency of search. While there is evidence that search efficiency improved there was no evidence that being able to predict forthcoming scenes led to a greater improvement over the random presentation of scenes.

The second reason why we might have failed to find an effect of sequence in Experiment 1 is that the task was too easy. One concern with Experiment 1 was the low average error rates and short RTs associated with target present responses (an average error rate of 11% and 1424 ms RT for target present scenes). It is possible that the failure to find an effect of sequence is a consequence of a floor effect.

Experiment 2 addressed these proposed explanations to introduce a contingency with respect to target presence within scenes, such that half of the scenes always held a target, whereas the remaining scenes never held a target. If participants could learn this contingency over time then target present responses could be made without fixating targets. If being able to predict scene order influenced the learning of this contingency then we should find evidence of target present responses being made without fixating targets in predictable versus randomised scenes. Second, in order to remove the floor effect as a possible explanation of the failure to find an effect of sequence, the discrimination of targets from backgrounds was made marginally more difficult. This difficulty was achieved by a closer blending of the target and background luminance levels.

2.3 RSST Experiment 2: Detecting targets when fixed to scenes but appearing in pseudo-randomised locations

2.3.1 Introduction

In Experiment 2, a contingency between target presence and scenes was established. Half of all scenes were target present and half target absent, meaning that if an individual scene had a target in the first block, there was always a target in that scene in all following blocks (see Figure 10). Target identity continued to vary across scenes. We predicted that participants would be able to use knowledge of forthcoming scenes to make target present and absent responses more efficient, but that this would only be possible when scenes were presented in a consistent sequence. Despite the fact that participants were instructed to fixate targets before responding, the ability to predict forthcoming scenes should influence eye movement behaviour once the contingency between scenes and targets has been learnt.

2.3.2 Method

2.3.2.1 Stimuli

In Experiment 2, each scene either always contained a target or never contained a target. 20 scenes always contained one of 20 targets (see Figure 10 below) and 20 scenes never contained targets. To address the concern that target detection may have been too easy in Experiment 1 for effects of sequence to emerge, target detection was made harder in Experiment 2. This was achieved by matching the targets to the area of the background in relative brightness and contrast. For example, if the randomly assigned location for a target was in the shadow of a tree, the light level of the target was lowered so as to be in keeping with the natural objects in that part of the scene.

Figure 10. Three targets located in three different locations in a scene

2.3.2.2 Participants

36 participants (26 females, aged between 19-30, M = 20.72, *SD* = 2.19) were tested in Experiment 2. All participants were undergraduate or postgraduate students of the University of Southampton.

2.3.3 Results

The data were analysed as in Experiment 1. Initially we examined behavioural data to see if any advantage was present when scene order was predictable, followed by examination of the eye movement data to reveal potential changes in cognitive processing.

2.3.3.1 Behavioural data

2.3.3.1.1 Error rates

The main effects of Block and Target were significant ($F(7, 245) = 11.18$, $p < .001$, $\eta^2_G = .042$; $F(1, 35) = 194.68$, $p < .001$, $\eta^2_G = .40$; see Figure 3). Errors reduced between block one (M = 17.6%, SD = 13.5) and block 8 (M = 12.1%, SD =

12.2) and less errors were made on absent (M = 5.98%, SD = 7.10) than present trials (M = 21.20%, SD = 11.60). The main effect of sequence, and interaction involving sequence, did not reach significance (all F ratios < 1.72).

2.3.3.1.2 RTs

The main effects of target type and block were significant (F(1, 35) = 120.53, p < .001, η^2_G = .269; F(7, 245) = 27.85, p< .001, η^2_G = .095; see Figure 4). RTs speeded from block one (M = 5051 ms, SD = 4598) to block 8 (M = 2938 ms, SD = 1267) and were faster on present (M = 2319 ms, SD = 895) than absent trials (M = 4759 ms, SD = 2922). The interaction between block and target type was significant (F(7, 245) = 19.50, p < .001, η^2_G = .035). Target absent RTs were significantly higher than in target present trials at both block 1 (both p < .001) and block 8 (both p < .001). RTs in both target types reduced between blocks 1 and 8 (both p < .001). RTs reduced with block more on absent than present trials (p < .001). There was no main effect of, or any significant interactions, involving sequence (all F ratios < 1.87).

2.3.3.2 Eye movement measures

2.3.3.2.1 Total number of fixations

The main effects of block and target type were significant (F(7, 245) = 29.59, p < .001, η^2_G = .102; F(1, 35) = 167.82, p < .001, η^2_G = .355; see Figure 5). The number of fixations reduced from block one (M = 14.9, SD = 1.24) to block 8 (M = 8.13, SD = 4.39) and was greater on absent (M = 14.70, SD = 9.21) than present trials (M = 2.46, SD = 2.49). The interaction between target type and block was significant (F(7, 245) = 24.91, p < .001, η^2_G = .046). Fixations in target absent trials were significantly higher than in target present trials at both block 1 (both p < .001) and block 8 (both p < .001). Fixations reduced in both target types between blocks 1 and 8 (both p < .001). Fixations reduced with block more on target absent than present trials (p < .001). Neither the main effect nor any interaction involving sequence reached significance (all F ratios < 1.72).

2.3.3.2.2 Mean fixation duration

The main effects of block and target type were significant (F (7, 245) = 9.58, p < .001, η^2_G = .014; F(1, 35) = 19.20, p < .001, η^2_G = .021; see Figure 6). Fixation durations reduced from block one (M = 236 ms, SD = 33.9) to block 8 (M

= 224 ms, SD = 29.4) and were longer on absent (M = 231 ms, SD = 28.10) than present trials (M = 222 ms, SD = 33). The reduction with block was greater on present than absent trials. There was a significant interaction between block and target type ($F(7, 245) = 2.73$, $p = .010$, $\eta^2_G = .003$). Fixation durations decreased more over target present than target absent trials (p = .034).

The three-way interaction between block, target type and sequence was significant ($F(7, 245) = 2.11$, $p = .043$, $\eta^2_G = .003$). The decrease in mean fixation duration over blocks in the target present trials was greater in the consistent than randomised sequence condition (see Figure 6). However, post hoc contrasts revealed this interaction to rely on differences in block one only (where no prior learning could have occurred). The interaction did not reach statistical significance when the first block was removed from the data. Neither the main effect nor any other interaction involving sequence reached significance (all F ratios < 1.20).

2.3.3.2.3 Time to fixate target

The main effect of block reached significance ($F(7, 245) = 13.66$, $p < .001$, $\eta^2_G = .088$; see Figure 7), with the time to fixate reducing from block one (M = 1945 ms, SD = 1178) to block 8 (M = 1416 ms, SD = 486). Neither the main effect of sequence order nor the interaction between sequence and block reached significance (all *F* ratios < 0.19).

2.3.3.2.4 Verification times

The main effect of block was significant ($F(7, 245) = 18.19$, $p < .001$, $\eta^2_G = .092$; see Figure 8). Verification times reduced from block one (M = 1115 ms, SD = 507) to block 8 (M = 828 ms, SD = 270). The main effect of sequence did not reach significance (F = 0.08). The interaction between block and sequence was significant ($F(7, 245) = 2.47$, $p = .018$, $\eta^2_G = .016$), indicating the time to verify targets was longer in the consistent sequence than the randomised sequence condition. As with mean fixation durations, post hoc contrasts revealed this finding relies on differences in block one relative to all other blocks and removing this block removes the interaction.

2.3.3.2.5 Likelihood of fixating the target prior to correct response

The likelihood of fixating the target prior to a correct response was computed for each participant. The main effect of block was significant ($F(7, 245) = 2.91$, $p = .006$, $\eta^2_G = .024$; see Figure 9). The likelihood of fixating the target prior to response decreased from block one (M = 88%, SD = 10.1) to block 8 (M = 83%, SD = 13.5). Neither the main effect of sequence nor the interaction between block and sequence reached significance (all F ratios < 1.14).

2.3.4 Discussion

Experiment 2 explored if establishing a contingency between target presence and scenes would enhance target detection when forthcoming scenes could be predicted relative to when they could not be predicted. Two results are striking. First, the improvements in performance over blocks found in Experiment 1 were also found in Experiment 2. Second, as in Experiment 1, sequence did not influence either behavioural or eye movement measures. Sequence order did interact with block for mean fixation duration and verification time, but in both cases the effect of sequence order was confined to the first block alone (where the consistent sequence condition led to longer durations and verification times than in the randomised condition). As targets present in the first block are the only ones that can’t be influenced by learning scene contingencies (with no earlier experience to draw on), we must interpret these interactions with sequence order to reflect chance effects of target placement and do not consider them further.

One piece of evidence that might be interpreted as consistent with participants learning the contingency between scenes and target presence is the likelihood of fixating targets before responding. There is a clear reduction in targets being fixated before a correct response, which could indicate that participants are able to identify the scene as containing a target without a need to search and fixate it. This reduction is about 5% over 8 blocks, with 83% of targets still being fixated before response in block 8. It is, however, an effect found in Experiment 1 where there was no contingency between scenes and targets. We consider the reduction in the likelihood of fixating targets over blocks before responding to reflect an enlarged functional field of view emerging over blocks.

Experiment 3 aimed to replicate this finding. Specifically, it explored whether the ability to predict forthcoming scenes might improve search for targets. In Experiment 3, all targets were fixed to specific scenes, as in Experiment 2, but 50% of the targets were fixed to the same locations in scenes. In holding target position constant for 50% of targets, participants might reveal evidence of the benefit of predicting forthcoming scenes by making fixations directly to target locations, which may decrease errors and reduce RTs.

2.4 RSST Experiment 3: Detecting targets in predictable scenes and locations

2.4.1 Introduction

As in Experiment 2, half of the scenes (20 scenes in total) were presented with no targets within them on each of the eight presentations and half with targets always present on each repetition. However, on half of the target present scenes (10 scenes out of 40 for each route) targets were always in same location of the scene and half were presented with targets varying in location (see Figure 11). Otherwise all details were as described in earlier experiments. As with Experiments 1 and 2, we predicted that behavioural and eye movements measures should reveal a benefit of being able to predict forthcoming scenes, especially when target position could also be predicted.

2.4.2 Method

2.4.2.1 Stimuli

Targets were either not fixed to scene identities (target absent trials), present in scenes (varying locations, see Figure 10) or present in scenes in the same location (fixed locations, see Figure 11).

Figure 11. Three targets located in one location in a scene.

2.4.2.2 Participants

40 participants (28 females, aged between 18-33, M = 21.55, *SD* = 3.64) were tested in Experiment 3. All participants were undergraduate or postgraduate students of the University of Southampton.

2.4.3 Results

The data were analysed as in Experiment 2 but with an additional level on the Target factor. Targets could be either absent, present within scenes (varying locations) or fixed to scenes and locations. As before, we examined the behavioural data to establish whether any general benefit in search was present in the consistent sequence over the randomised sequence, followed by an examination of the eye movement data to reveal changes in underlying cognitive processing. Interactions between block and target are explored by comparing the difference between block 1 and block 8 between targets types (targets in fixed and varying positions, and scenes without targets), using pairwise t-tests with a Bonferroni adjustment [$p < .006 = .05/9$]).

2.4.3.1 Behavioural data

2.4.3.1.1 Error rates

The main effects of block and target type were significant (*F*(7, 273) = 14.102, $p < .001$, $\eta^2_G = .033$; *F*(2, 78) = 94.661, $p < .001$, $\eta^2_G = .172$; see Figure 3). Error rates reduced from block one (M = 13.5%, SD = 13.07) to block 8 (M = 8.19%, SD = 10.8) and were lower on absent (M = 3.2%, SD = 4.89) than both types of present trials (varying locations, M = 12.8%, SD = 12.2, fixed locations M = 12.6%, SD = 11.7, both p < .001). The interaction between target type and block was significant (*F*(14, 546) = 4.046, $p < .001$, $\eta^2_G = .020$). There were significantly fewer errors in target absent than both target present trials at both block 1 (both p < .001) and block 8 (both p < .001). Targets in fixed locations generated significantly more errors than those in varying locations in block 1 (p = .006) but significantly fewer errors in block 8 (p = .002). Both the targets present in fixed locations and trials without targets significantly reduced the number of errors between block 1 and block 8 (both p < .001) and there was no significant change in error rate between blocks 1 and 8 in targets present in varying locations. Neither the main effect nor any interaction involving sequence reached significance (all F ratios < 1.37).

2.4.3.1.2 RTs

The main effects of block and target type were significant (*F*(7, 273) = 95.31, $p < .001$, $\eta^2_G = .125$; *F*(2, 78) = 97.79, $p < .001$, $\eta^2_G = .414$; see Figure 4). RTs decreased from block 1 (M = 3610 ms, SD = 2769) to block 8 (M = 2032 ms, SD = 1056) and were slower on absent (M = 4045ms, SD = 2270) than either present (varying locations, M = 1756ms, SD = 571, fixed locations M = 1812ms, SD = 657, both $p < .001$). The interaction between target type and block was significant (*F*(14, 546) = 55.70, $p <.001$, $\eta^2_G = .071$). RTs were significantly longer in target absent than either target present trials at both block 1 (both $p < .001$) and block 8 (both $p < .001$). Targets in fixed locations generated longer RTs than those in varying locations in block 1 only ($p < .001$). All target types significantly reduced RTs between blocks 1 and 8 (all $p < .001$). Pairwise comparisons also revealed that RTs significantly decreased between blocks 1-8 in target absent trials when compared to both target present trials (both $p < .001$). Neither the main effect nor any interaction involving sequence reached significance (all F ratios < 0.94).

2.4.3.2 Eye movement measures

2.4.3.2.1 Total number of fixations

The main effects of block and target type were significant ($F(7, 273) = 99.12$, $p < .001$, $\eta^2_G = .199$; $F(2, 78) = 136.03$ $p < .001$, $\eta^2_G = .448$; see Figure 5). The number of fixations reduced between block one (M = 11.24, SD = 9.43) and block 8 (M = 6.17, SD = 3.70) and was higher on absent (M = 13.40, SD = 7.38) than both types of present trials (varying locations, M = 5, SD = 1.79, fixed locations M = 5.08, SD = 1.94, both $p < .001$). The interaction between the block and target type was significant ($F(14, 546) = 67.20$, $p < .001$, $\eta^2_G = .140$). Fixations in target absent trials were significantly higher than in either target present trials at both block 1 (both $p < .001$) and block 8 (both $p < .001$). Fixations reduced in all target types between blocks 1 and 8 (all $p < .001$). There was a greater reduction in target absent fixations than either target present trials (both $p < .001$). Neither the main effect nor any interaction involving sequence reached significance (all F ratios < 0.63).

2.4.3.2.2 Mean fixation duration

The main effects of block and target type were significant ($F(7, 273) = 14.08$, $p < .001$, $\eta^2_G = .024$; $F(2, 78) = 13.26$, $p < .001$, $\eta^2_G = .026$; see Figure 6). Fixation durations reduced from block one (M = 228 ms, SD = 31.2) to block 8 (M = 214 ms, SD = 30.6) and were longer on absent (M = 224 ms, SD = 24.5) than both types of present trial (varying locations, M = 214 ms, SD = 32.50, fixed locations M = 214 ms, SD = 32.80, both $p < .001$). There was no difference between the two types of present trials. The interaction between target type and block did not reach significance ($F = 1.15$). Neither the main effect nor any interaction involving sequence reached significance (all F ratios < 2.35).

2.4.3.2.3 Time to fixate target

The main effect of block was significant ($F(7, 273) = 28.517$, $p < .001$, $\eta^2_G = .111$; see Figure 7) and time reduced from block one (M = 1445 ms, SD = 705) to block 8 (M = 965 ms, SD = 308). The main effects of target type and sequence did not reach significance (both F ratios < 1.159). The interaction between block and target type was significant (F(7, 273) = 4.391, p < .001, η^2_G = .014). The time to first fixate targets reduced more when targets were fixed than when they were not tied to specific locations. When the first block is omitted from the data the main effect of target is significant (F(1, 39) = 7.867, p = .007, η^2_G = .003), with targets in fixed locations (M = 1042 ms, SD = 348) being found faster than those in varying locations (M = 1082 ms, SD = 385), and the interaction with block does not reappear. Neither the main effect nor any interaction involving sequence reached significance (all F ratios < 1.36).

2.4.3.2.4 Verification times

The main effects of block was significant (F(7, 273) = 35.33, p < .001, η^2_G = .114, F(1, 39) = 31.29, p < .001, η^2_G = .009; see Figure 8). Verification times reduced from block one (M = 929 ms, SD = 453) to block 8 (M = 633 ms, SD = 173) and were higher in targets in fixed (M = 695 ms, SD = 212) rather than varying locations (M = 667 ms, SD = 207). The interaction between target type and block was significant (F(7, 273) = 3.75, p < .001, η^2_G = .010). The reduction of verification times over blocks was greater when target locations are fixed than not, but this difference was dependent on performance in block 1 as removing these data from the analysis removed the significance of the interaction. Neither the main effect nor any interaction involving sequence reached significance (all F ratios < 0.97).

2.4.3.2.5 Likelihood of fixating the target prior to correct response

The main effects of block and sequence were significant (F(7, 273) = 4.88, p < .001, η^2_G = .023; F(1, 39) = 4.80, p = .034, η^2_G = .003), see Figure 9). The likelihood of fixating a target prior to response reduced from block 1 (M =91%, SD =10.7) to block 8 (M = 84%, SD = 13.5) and was lower when targets appeared in a consistent (M =87%, SD = 13.3) than random sequence (M =89%, SD =11.7). The main effect of target type did not reach significance (F = 1.21) No interactions were significant (all F ratios < 1.59).

2.4.4 Discussion

Some of the results of Experiment 3 are very similar to those found in Experiments 1 and 2. First, the improvement in performance over blocks found in Experiments 1 and 2 was also found in Experiment 3. Second, the more marked improvement in performance over blocks on absent than present trials found in Experiments 1 and 2 is also found in Experiment 3. Third, the lack of a reliable effect of sequence order on behavioural and the majority of eye movement measures found in Experiments 1 and 2 was also replicated in Experiment 3.

One key result of Experiment 3 suggests that being able to predict forthcoming scenes may have influenced eye movements. The reduction in probability of fixating targets before responding present was also found in Experiment 3 and was more striking in the consistent order relative to the randomised order. We interpret this to result from an increasing functional field of view, so that correct identification was easier to do, and occurred more quickly, when scenes are presented in the consistent order. Interestingly, while this was certainly prompted by fixing targets to scenes, the effect does not interact with target type. It is likely then that awareness of one contingency with scenes (some locations always have targets) may have allowed an awareness of other contingencies (some scenes always have targets), which allows for more confident identification of targets at a distance, when these scenes can be prepared for in the consistent sequence.

2.5 Analysis of individual differences across RSST Experiments 1-3

In a final effort to find evidence for an effect of order on search we explored if an influence of scene order on search, if present at all, might depend on some attribute that varies across participants. If it is the case that order effects depend on an attribute that varies across individuals, then it might be that order effects are present in some participants but not in others, making them hard to detect using group studies that take no account of varying attributes.

To explore the possibility that order effects on search might depend on attributes that vary across individuals, we turn now to the individual difference data collected for all participants across Experiments 1-3. The change in response times over blocks in absent and present trials reported across Experiments 1-3 primarily reflect change in two eye movement measures: (1) the number of fixations made before responding absent and (2) and target verification time. The reduced number of eye movements speeding RTs on absent, and reduced verification times speeding RTs on present trials.

To provide a single index of speeding over blocks, linear slopes were calculated relating to the change in number of fixations and verification times to the logarithm of block (the logarithm being used to linearize the fit of data to block) for each participant. The gradient of the lines relating number of fixations and verification times to the log of the block number is independent of their intercepts. The gradient captures the amount of change over blocks while factoring out variation in overall response times across experiments and individuals. Relatively steep gradients (i.e. more negative) are associated with greater change over blocks than relatively shallow gradients (i.e. more positive). The measures of individual differences described in Experiment 1 were used as predictors of the gradients of these regression slopes. The data collected from Experiments 1-3 are displayed below (see Table 1). The significance of the correlation was determined using Bonferroni adjusted alpha levels of .0125 (.05/4). The data are presented in Table 1.

Table 1. Correlations between individual differences measures and the slopes for absent fixations and verification times.

		Absent		Present	
		Consistent	Randomised	Consistent	Randomised
Experiment 1					
WM	Visuospatial	.011	-.082	.101	.059
	Verbal	.019	.016	.063	-.014
ANT	Orienting	-.490*	.117	-.434*	.227
	Alerting	.054	.195	-.091	-.14
	Executive Control	.043	.061	.031	-.034
Experiment 2					
WM	Visuospatial	.029	.246	-.027	.139
	Verbal	.029	.021	-.072	.131
ANT	Orienting	-.393	.002	-.255	.019
	Alerting	.211	.043	-.044	.073
	Executive Control	-.303	.17	-.267	.22
Experiment 3					
WM	Visuospatial	-.265	-.003	-.315	.384
	Verbal	-.113	-.06	-.177	.163
ANT	Orienting	.02	-.129	-.322	.348
	Alerting	.248	-.036	-.096	.434*
	Executive Control	-.006	.245	.118	.267

The individual differences data are informative. In Experiment 1, attentional orienting is correlated with change in the number of fixations made on absent trials and verification times on present trials, but only in the consistent sequence. We suggest that these data show that individuals with good orienting skills might use knowledge of forthcoming scenes to prioritise locations for efficient target search. If so, the differentiation of performance by attentional orienting only emerges when target location and presence is fully randomised (Experiment 1), and does not reappear when target presence or location can be predicted from earlier experience (Experiments 2 & 3).

In Experiment 3 a significant correlation is present between attentional alerting and a reduction in verification times in the randomised order condition. We suggest these data show that those high in alerting show an enhanced ability to detect targets at onset, both in and out of repeated locations when the contingency between scenes and targets are high, but only when the scene itself could not be predicted. The absence of a similar relationship in the consistent sequence condition may indicate that scene order provides the necessary information for all participants. It is noteworthy that there were no significant correlations with visuospatial or verbal WM capacity.

2.6 General discussion

In this study, we explored whether being able to predict forthcoming scenes improves the search for targets. In all experiments, spatially and temporally related scenes were shown where neighbouring scenes were consistently ordered or presentation was randomised. We hypothesized that repeatedly presenting spatially and temporally related scenes would lead to improved search for targets when repeating unrelated scenes would not (i.e. an effect of temporal sequence). In Experiment 1 target presence and location were randomised for each presentation of a scene. In Experiment 2 target presence was fixed to scenes. In Experiment 3 both target presence and location were repeated across presentations of a scene.

The conclusions to be drawn from the analyses of condition means are simple. There are reliable effects showing that search improves over repeating blocks; that the improvement in search over blocks is stronger on absent than present trials; and while sequence order did not affect the speed or accuracy of responses; the functional field of view used to detect targets increased with blocks when target presence and location was predictable based on earlier exposure.

In Experiments 1 and 2 we found no evidence of sequence having any effect on eye movements but this is not the case in Experiment 3. When targets are fixed to scenes and positions in scenes then there is evidence that the functional field of view used to detect targets is significantly increased when scenes are presented in a spatial-temporal order.

Further evidence for an effect of scene order on search was sought in the individual difference measures. The results suggest orienting and alerting networks may be important in being able to utilise scene order information to enhance search. Orienting may be particularly important when there is no contingency between scenes and targets while alerting may be important when contingencies exist but the presentation of specific scenes cannot be predicted. In other words, when the image to be presented cannot be prepared for, those with a higher alerting network capacity have an advantage in detecting targets that can be predicted by both scene and location. When searching for targets in the real world it may be that selecting for those high in orienting and alerting skills may be worthwhile if target detection is to be maximised. We consider these regressions to form the basis for further work to consider.

An intrinsic issue with trying to test for scene context effects based in temporal order is the manner of scene presentation. It is possible that static presentations of images to move around a real-world environment (such as Google Maps Street View, to use a commercial example) are unsuited to best explore the role of temporal order on scene learning. An individual searching in the real world has true agency, whereas the route presented to individuals is distinctly linear, with no control on the direction the perspective takes. Future work should consider how an immersive environment can be constructed that allows for restructure in a way that presents the environment in as fluid a manner as possible. What our experiments have demonstrated is that temporal sequence effects can be produced with experience, but the environment must offer some incentive that benefits search beyond a simple cue of the scene to come. In addition, some individuals may be more responsive or reliant on their environment acting as a cue for search. Whether these individuals have a distinct advantage in the real world remains a question to be answered.

The present study explored how being able to predict forthcoming scenes might influence search for targets. While the analysis of mean RTs and accuracy revealed no effect of scene order on performance there were subtle influences on eye movement behaviour. There were also relationships between the improvement in search over blocks and orienting and alerting as measured in the ANT. While the influence of being able to predict forthcoming scenes on search is subtle, it is present and might be especially important in the real-world application of these studies.

Chapter 3 The effect of improving working memory on target search in repeated routes

Prepared for publication: Tew, O., Godwin, H. J., Garner, M., Hadwin, J. A., Liversedge., S. P. & Donnelly, N. *The effect of improving working memory on target search in repeated scenes*

3.1 Introduction

The way in which we use knowledge of forthcoming scenes to guide search for targets has recently been the subject of experimentation (see Chapter 2). The focus of these experiments was to establish whether being able to predict forthcoming scenes would speed target detection and increase accuracy. Tew et al. had participants search for targets placed in a series of spatially and temporally related photographs taken along a suburban route. The photographs represented a consistent order and were learnt over eight repetitions (henceforth the repeated scenes search task [RSST]). The consistent order condition was compared to a condition where scene order was randomised.

To explore the influence of being able to predict forthcoming scenes on target search, the contingencies linking targets to scenes and locations within scenes were varied across experiments using the RSST paradigm. Target appearance ranged from being fully randomised across scenes and locations to being fixed to locations within specific scenes. The results showed performance in all conditions benefitted from practice, but that target accuracy and the speed with which targets were detected (measured by eye movements assessing the time to the target location) was dramatically improved when fixing targets to locations in scenes. The improvement in search was particularly striking for participants whose attention systems strongly alert and orient participants attention. The individual strengths in the alerting and orienting networks were measured by the attentional network test (ANT, Fan et al., 2002).

One surprising finding was the lack an effect of either visuospatial or verbal working memory (WM, assessed by a 3-step n-back task) on performance improvement (Tew et al., in prep). Considering the importance of WM faculties within current cognitive models (Au, Buschkuehl, Duncan & Jaeggi, 2016; Redick et al, 2016), particularly including search (Hollingworth, 2006; Hout & Goldinger, 2010), the control of attentional processes (Engle, 2002; Unsworth & Spillers, 2010; Colflesh & Conway, 2007) and accessing long term memory storage (Kane & Engle, 2000), the absence of any influence of WM on target search was unexpected.

There are two competing explanations for the null result with respect to WM on improvements in target search. First, that WM plays no role in improving target search in a task where scenes can be used as cues to upcoming target presence. Based on the literature available, we consider this to be unlikely. Second, that the RSST itself failed to show an effect of WM on improvement in target search for some other reason. One potential reason is that the use of the randomised control condition may have worked against participants learning spatio-temporal relationships across scenes in the control condition, which also may have affected participants learning in the consistent sequence condition. This might have been the case given that randomising scene order removed the spatio-temporal link across scenes. If randomising scene order had this effect on participants, then removing it might encourage participants to learn the spatio-temporal relationships that exist across scenes, which additionally might allow an underlying influence of WM on learning spatio-temporal relationships to emerge. The first goal of the present study is to repeat Experiment 3 from that study (Tew et al, in prep), where a contingency exists between scenes, locations and target presence, but where participants only experience ordered sequences. It was believed that, of the three designs present in the earlier study, Experiment 3 afforded the greatest opportunity to learn from earlier blocks in identifying which scenes did and did not contain targets, as well as where they were to be found (e.g. targets in a fixed location).

Further evidence for a role of WM in learning spatio-temporal relationships across scenes might be found by attempting to improve target search by increasing both visuospatial and verbal WM. The dual n-back task (as described in Jaeggi, Buschkuehl, Jonides, & Perrig, 2008) provides participants with an array on which spatial locations (visuospatial stimuli) are activated while a letter is relayed over headphones (verbal stimuli). Accurate performance in both visuospatial (location) and verbal (letter) identification increases the number of "steps" (n) in the training task, increasing the number of items to be remembered by 2 for each step. This means that, rather than simply becoming practised at a task in which two or three items need to be remembered in a long sequence (e.g. a 2 or 3 step n-back with one target, used as training in Dahlin, Nyberg, Bäckman, & Neely, 2008; Li et al., 2008), the number of items needed to be stored is constantly shifting, and includes two categories that need to be manipulated. Prolonged use of the n-back task has been shown to improve both visuospatial and verbal WM performance (Owens, Koster & Derakshan, 2013; Jaeggi, S. M., Buschkuehl, M., Shah, P., & Jonides, 2014).

Another method of increasing WM is via transcranial direct-current stimulation (tDCS) to the dorsolateral prefrontal cortex (LDLPFC). tDCS has been previously used as an intervention in order to stimulate the motor cortices (Reis et al., 2009, Boggio et al., 2006) as well as improving recognition memory in adults with Alzheimer's (Boggio et al., 2009). The procedure has also been show to enhance WM ability on a variety of tasks (Richmond et al, 2014; Fregni et al., 2005; Seo, Park, Seo, Kim, & Ko, 2011; Zaehle, Sandmann, Thorne, Jancke, & Herrmann, 2011). Stimulation to the LDLPFC increased verbal WM and enhanced other untrained WM tasks, in comparison to those who received no stimulation (Richmond et al, 2014). When training on a dual n-back task (with either active or sham tDCS to the LDLPFC) a greater benefit of deployment was found in the active rather than sham groups, with a substantial difference between the groups still being evident one month following stimulation (Martin et al, 2013).

In summary, the present study has three aims. The first is to replicate the findings of Tew et al using the RSST. Second, to establish whether WM influences target search in the RSST when targets are linked to scenes and locations, and no randomised condition is presented. Finally, to explore if increasing WM capacity by training on the n-back task or applying tDCS improves target search.

3.2 Method

3.2.1 Participants

Forty participants were recruited (24 female; aged 18-27, M: 21, SD: 2.2). Participants were members of the University of Southampton and had been contacted via online advertisements or were invited to sign up via a dedicated website. Participants were compensated for their time either with course credits (a certain number of which need to be attained by participating in local experiments for psychology undergraduates) or with a small monetary payment (£6/hour). All participants performed in the same baseline condition. Following the baseline condition, twenty participants were allocated to the WM training intervention group and to the tDCS intervention group (14 Female; aged 18-27, M: 20.50, SD: 2.417). The data from two participants in the WM training intervention were corrupted and couldn't be used, leaving 18 participants (9 Female; aged 20-26, M: 21.50, SD: 1.855). Within each intervention group, half were randomly allocated to active (adaptive training and active tDCS) and half to sham (non-adaptive training and sham tDCS) intervention groups.

3.2.2 The Repeated Scenes Search Task (RSST)

In the RSST participants are shown 40 photographs eight times and asked to search for targets presented within these scenes. When presented in an ordered sequence the photographs are spatio-temporally ordered to define a route (the consistent sequence condition from Tew et al., in prep). The participant's task was to search for a hand-tool that might be present within each scene. Participants received audio feedback. The photographs were taken while walking through a real-world suburban neighbourhood.

A contingency was set so that target presence and location were linked to scenes. Targets were presented on 50% of scenes. Ten targets were fixed to locations within scenes and ten varied in location but always appeared in the same scenes. Targets were presented in randomised locations (but confined to naturalistic positions in the scene). The version of the RSST used here was identical to that used in Experiment 3 but without also showing the randomised scene condition (Tew et al., in prep).

3.2.3 Visuospatial Working Memory (WM)

Participants were presented with 200 trials of a Change Detection Task (CDT) consisting of a memory and a test array[4]. Participants were presented with an array of red and blue rectangles on both sides (left and right) of a fixation cross, and instructed to remember the orientations of target items (red rectangles) from memory (100ms) to test (1000ms) arrays. The interval between memory and test arrays was 900 ms.

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[4] In Chapter 2 of this thesis a 3-step-n-back task was used to assess visuospatial and verbal WM. However, as this task is conceptually very similar to the adaptive dual-n-back training program, two sufficiently different tasks that assess the same cognitive resources were used both here and in Chapter 4

In half of the trials, the orientation of one red rectangle changed from the memory array to the test array. Participants responded used a numerical keyboard button press to indicate whether the orientation of one of the red rectangles changed (“1” key press) or did not (“0” key press) change. The CDT task produces accuracy and RT measures of visuospatial WM and has been reliably used to assess visuospatial WM differences between participants (Owens et al., 2013; Vogel et al, 2006).

3.2.4 Verbal WM

Participants performed a Digit Span Task (DST; WAIS, Wechsler, 2008) where a set of numbers was presented visually for participants to recall them in forward (forward span) or reverse order (backwards span). The number of digits presented to participants increased until the participant failed to input the complete number correctly twice. The maximum digit reached in the backwards span was used as an assessment of verbal WM.

3.2.5 Attentional Network Test (ANT)

In the ANT participants are required to fixate on a central point on a screen. Five arrows appear above or below the central point, and participants are required to identify whether the middle (3rd) arrow is pointing left or right. The flanking arrows can either point in the same direction as the arrow (congruent) or in the opposite direction (incongruent). The target location may be cued prior to each trial. The time to respond to the target, cued or otherwise, and either flanked by congruent or incongruent distractors, are calculated to produce measures of the orienting, alerting and executive control networks (Fan et al, 2002). Participants completed the ANT in the baseline session only.

3.2.6 Intervention

After completing the baseline phase, participants were randomly assigned to an intervention group.

3.2.6.1 WM Training Intervention

Participants in the WM intervention group completed the dual n-back task on their home computers after first completing the tasks in the baseline phase. Participants were presented with a 3x3 grid of blank squares, one of which illuminated. At the same time that the square was illuminated, a single letter was relayed to the participant via headphones (see Figure 12 for an example of correct responses repeating after 2 steps, reproduced from Jaeggi et al, 2008). The task was to report if either the visual or verbal stimulus was repeated from *n*-stages earlier. Participants responded using a keyboard. One key was used to report a match between the spatial location ("a" key press) and another for a match between letters ("l" key press). If both the location and the letter are matched, both keys were to be pressed simultaneously.

Participants completed 20 blocks of 20 trials for a total of 15 days. Breaks in training were allowed every 5 days, for no longer than two days. For participants completing the adaptive training, performance at 90% or better on both locations and letters led to an increase in the number of steps to be counted back in the block, up to 4-steps (requiring the maintenance of 8 pieces of information). Poor performance led to a reduction in the number of steps. Participants completing the non-adaptive training remained at 1-step throughout (hereafter labelled as sham).

These participants were advised to use headphones and to complete the training at a time when they would not be disturbed. The online training was operated via a server hosted by Birkbeck College (University of London).

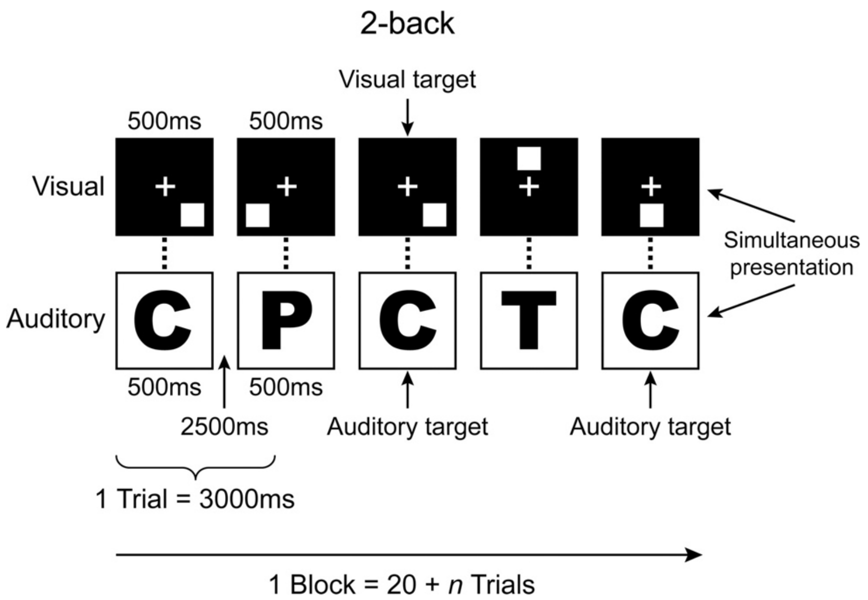

Figure 12. Dual n-back WM training showing a match in both auditory and visual targets

3.2.6.2 Transcranial Direct Current Stimulation (tDCS)

Approximately 15 days later after completing the baseline phase, participants returned to the lab and received either 20 minutes of 2 mA anodal stimulation to the left dorsolateral prefrontal cortex (LDLPFC) or a sham stimulation. The sham stimulation initiated a few seconds of active stimulation before continuing to activate a timer, with no stimulation applied for the following 20 minutes. The stimulations were applied immediately before completing a second repeated scenes task, and the associated battery of individual difference measures.

3.2.7 Procedure

All participants were tested for normal visual acuity (a minimum 1.0 decimal VA at a distance of approximately 1m) using the Freiburg Visual Acuity Test (Bach, 1996) and all passed the City University Colour Vision Test (3rd edition; 1998) indicating they had normal colour vision. Prior to beginning the Experiment, a 9-point calibration was run to ensure no recording issues with the eye-tracker set-up. Each calibration point had no higher error than 0.5° of visual angle.

Following these measurements and an explanation of RSST, participants completed a single route during the first laboratory session. This was followed by the various individual difference measures reported above. Participants in the WM training group were given instructions on how to complete the WM training task and were provided with a unique link that allowed them to complete the task from their own computer. The participants then completed 15 training sessions, one per day. Either on the same day as the final training session or the day immediately following it, participants returned to the laboratory and completed a second run of the experimental procedures, including the second route in the repeated scenes task and the other individual difference measures. Participants in the tDCS group returned after a 15-day period and received either sham or active tDCS to the F3 area (the LDLPFC), before completing both the second session of the RSST and the individual difference battery.

Participants completed two routes in total, one prior to the intervention they would receive and one post-intervention. Therefore, participants were additionally counterbalanced against both route identity (A/B) and training/stimulation type (adaptive/non-adaptive n-back task, sham/active tDCS stimulation) yielding four groups in total, per intervention.

The experimental procedure was approved by the University of Southampton Ethics and Research Governance Office and the Ministry of Defence Research Ethics Committee (MoDREC), and followed the conventions of the Declaration of Helsinki. Full written consent was obtained from each participant after an explanation of the experimental procedure was provided.

3.2.8 Data Analysis

As with our earlier work (Tew et al., in prep), we explored several behavioural and eye movement indices of performance (error rates, reaction times [RTs], fixation durations, number of fixations and the time to fixate and verify targets. With the exception of error rates, all analysis was conducted on correct trials only. In line with our earlier study, we predicted that there would be reductions across blocks within sessions as participants gained experience with scenes, targets and locations. In other words, we predicted that both behavioural and eye movements measurements would reflect faster and more accurate search as participants completed more blocks. We also predicted that there would be a significant improvement in performance in the second session following both the active and non-active variants of the intervention. Finally, we predicted that in the active interventions, there would be a significant improvement made to visuospatial and/or verbal WM, which would facilitate significant improvement in that group compared to the control group.

3.3 Results

The results were analysed in four sections. In Section 1 behavioural and eye movement measures were analysed from performance in the RSST at baseline. These analyses sought to establish whether the results found in an earlier study using targets fixed to locations and scenes (see Tew et al., in prep; Experiment 3) were replicated in the present study. In Section 2 the relationship between the WM and attentional network measures and performance change over blocks in absent and present trials are explored via changes to eye movement behaviours. The slopes of number of fixations (target absent trials) and verification times (target present trials) were generated for each participant and correlated against the WM and ANT scores. We hypothesized finding a relationship between WM and reduction in number of fixations made on absent trials and verification times on present trials. In Section 3 the speed and accuracy of target search pre and post intervention is compared. The goal of this analysis is to explore if WM training or tDCS changes the speed and accuracy of target search relative to performance at baseline. Here, to aid clarity of presentation, only significant effects of Session (pre versus post intervention) or the interaction of Session with Group (active versus sham intervention) are reported. In Section 4, the efficacy of the WM training on increasing WM capacity is reported. Pairwise comparisons were Bonferroni corrected when appropriate.

3.3.1 Section 1: Baseline Performance

Behavioural and eye movement data were analysed in separate ANOVAs with two within-subjects factors: Block[5] (2-8) and Target type (3: target absent, varying location, fixed location) and one between-subjects factor: Group (WM training versus tDCS). The between-subjects factor was included to test whether the two groups of participants performed equivalently before intervention. Analyses of time before fixating targets and target verification time did not include data from absent trials (See Figure 13). Interactions with block were investigated with post-hoc comparisons using the second and last block and across target types. Comparisons were made between target categories (target absent, target in varying locations, target in consistent locations) at block 2 and block 8, as well as assessing any change between blocks 2-8 within targets. Our Bonferroni-adjusted alpha was .006 (.05 / 9). Consistent with our earlier work, if all pairwise comparisons were significant then another pairwise comparison was computed on the difference between the second and last block for each target type.

3.3.1.1 Behavioural measures

3.3.1.1.1 Error rates

The main effects of Target type and Block were significant ($F(2, 72) = 47.323$, $p < .001$, $\eta^2_G = .158$; ($F(6, 216) = 2.325$, $p = .034$, $\eta^2_G = .012$). Error rates were lower on target absent (3.37%) than present trials when targets appeared in fixed (10%,

[5] As the targets present in fixed locations can only benefit search (i.e. faster fixations, increased accuracy, etc. see Chapter 2) following exposure to block 1, the data from block 1 was excluded from all analyses.

$p < .001$) or varying locations (12.63%, $p < .001$). More errors were made on target present trials in varied than fixed locations ($p = .003$). Error rates reduced from 9.96% in block 2 to 7.37% in block 8. All other main effects and interactions failed to reach significance (all $F < 1.368$).

3.3.1.1.2 Reaction times (RTs)

The main effects of Target type (F (2, 72) = 111.424, $p < .001$, $\eta^2_G = .441$) and Block (F (6, 216) = 27.673, $p >.001$, $\eta^2_G = .087$) were significant. RTs were longer on target absent (3787ms) than on present trials when targets appeared in either varying (1920ms, $p < .001$) or fixed (1884ms, $p < .001$) location, but did not differ between types of target present trial. RTs reduced from 3108 ms in block 2 to 2167 ms in block 8.

The interaction between Target type and Block was significant (F (12, 432) = 7.214, $p >.001$, $\eta^2_G = .028$). RTs were significantly greater between target absent than both target present trials at both block 2 (both $p < .001$) and block 8 (both $p < .001$). Target present trials were not significantly different at either block 2 or block 8 (both $P > .1$). All target types reduced between blocks 2 and 8 (all $p < .006$). The difference in RT between blocks 2 and 8 was significantly greater in target absent trials than either target present trials (both $p < .008$). No other main effect or interactions reached significance (all F values < 1.795).

In summary, responses to target present trials were significantly less accurate and numerically slower when in varying than fixed locations. Responses to absent trials were more accurate but slower than to both types of present trials. Errors reduced and RTs speeded over blocks especially on absent trials.

3.3.1.2 Eye movements

3.3.1.2.1 Mean fixation durations

The main effects of Target type (F (2, 72) = 38.808, $p < .001$, $\eta^2_G = .054$) and Block (F (6, 216) = 2.325, $p < .001$, $\eta^2_G = .011$) were significant. Fixation durations were longer on target absent trials (212 ms) than either target present trials (196 ms and 196ms, both $p < .001$ for varying and fixed locations respectively). The difference in mean fixation duration between the target present trial types did not reach significance. Mean fixation duration reduced from 207 ms in block 2 to

197 ms in block 8. The interaction between Target, Group and Block neared significance, but did not reach it F (12, 432) = 1.641, p = .078, η^2_G = .007. No other main effects or interactions reached significance (all F values < 1.152).

3.3.1.2.2 Number of fixations

The main effects of Target type (F (2, 72) = 133.585, p < .001, η^2_G = .598) and Block (F (6, 216) = 46.932, p >.001, η^2_G = .089) reached significance. More fixations were made on target absent trials (12.556) than either target present trials (varying (4.785 and 4.739, both p < .001 for varying and fixed location trials respectively). There was no significant difference between target present trial types. The number of fixations reduced from a mean of 9.08 in block 2 to 6.17 in block 8. The interaction between Target type and Block was significant (F (12, 432) = 18.183, p >.001, η^2_G = .059). There were significantly more fixations in target absent trials both target present trials at both block 2 (both p < .001) and block 8 (both p < .001). Target present trials did not significantly differ at either block 2 or block 8 (both p > .038, not meeting the adjusted alpha of .006). The difference in fixations between blocks 2 and 8 was significantly greater in target absent trials than in either target present trials (both p < .001). No other main effect or interactions reached significance (all F values < 1.795).

3.3.1.2.3 Time to fixate

The main effect of Block was significant (F (6, 216) = 12.893, p > .001, η^2_G = .084). Time to fixate targets reduced from 883 ms in block 2 to 711 ms in block 8. The interaction between Target type and Block was significant F (6, 216) = 2.302, p = .036, η^2_G = .015). The time to fixate targets appearing in fixed locations reduced more from block 2 to block 8 than did the time to fixate targets in varying locations, although this was due to differences between targets in block 2 only, p = .057. No other interactions were significant (all F values < 1.818).

3.3.1.2.4 Verification time

The main effect of Block was significant (F (6, 216) = 13.697, p > .001, η^2_G = .092). Verification time reduced from 1033ms in block 2 to 805 ms in block 8. The interaction between Target type and Block was significant F (6, 216) = 2.347

p = .033, η^2_G = .012). Verification times reduced more for targets presented in fixed than in varying locations, although this was due to differences between targets in block 2 only, p = .031. No other interactions were significant (all F values < 1.906).

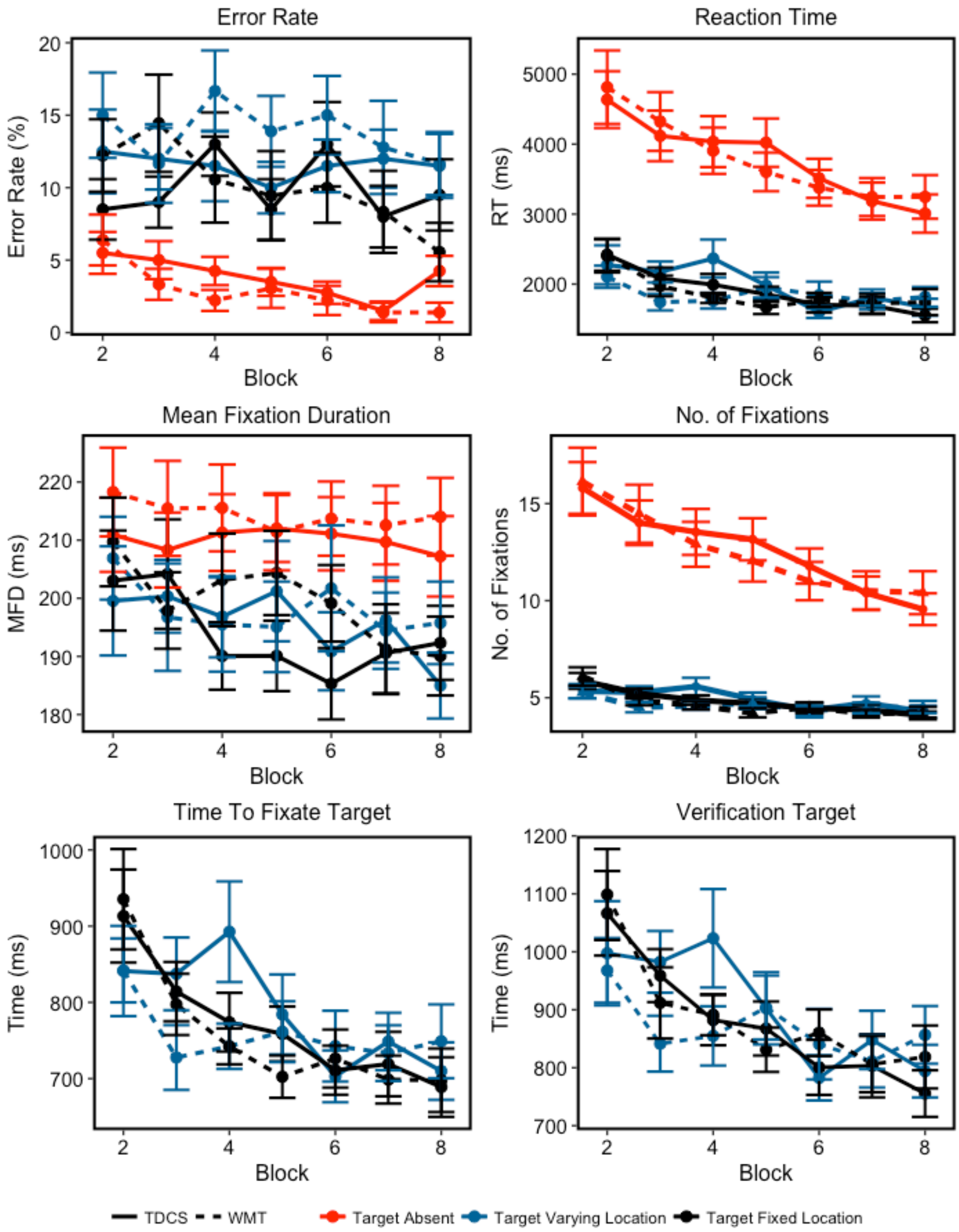

Figure 13. Analyses between experimental groups prior to intervention

The eye movement data show the duration of fixations reduced with block, as did the number of fixations (especially on absent trials). The time to fixate targets reduced with block most markedly for targets presented in fixed than varying locations. Additionally, the time to verify targets reduced more for targets appearing in fixed than varying locations. Considered with the behavioural data, the eye movements show the speeding of absent responses over blocks was associated with reduced number of, but longer, fixations. The increased accuracy of targets in fixed versus varying locations was associated with reduced fixation and verification times.

3.3.2 Section 2: Individual difference analyses of data prior to intervention

The data presented in Table 2 report the correlations between verbal and visuospatial WM and the ANT scores and the gradient of the reduction in number of fixations made on absent trials and verification time on present trials, characterised by a linear slope (across the logarithm of block, used to linearize the fit of data to block) for each participant (see Tew et al., in prep). The slope therefore reflects the degree of change over blocks between block 2 and block 8, with steeper (more negative) slopes indicating a greater demonstration of learning over the task, and shallower (more positive) slopes indicating as smaller demonstration of learning.

The correlations suggest that visuospatial WM is associated with a smaller reduction in the number of fixations made with blocks on absent trials and in the verification times made to targets presented in varying locations. The significant negative relationships suggest those high in visuospatial WM change performance less over blocks than those with low visuospatial WM, which is likely due to visuospatial WM supporting improved learning early in the task.

Table 2. Correlations between learning in RSST and cognitive faculty measures

		Absent Trials		Varying Location		Fixed Location	
Cognitive faculty	Measure	*r*	*p*	*r*	*p*	*r*	*p*
Verbal WM	Max. Digit	.364	.027	.356	.031	.333	.044
Visuospatial WM	Accuracy	.215	.194	.094	.573	.035	.836
	RT	-.441*	.006	-.482 *	.002	-.216	.194
Attentional Network	Orienting	.152	.382	-.061	.726	-.062	.726
	Alerting	-.051	.772	.103	.557	.132	.448
	Executive	.14	.424	-.011	.951	-.173	.319

* indicates correlation is significant to $p = .016$

3.3.3 Section 3: Group differences between sessions

The behavioural data from the pre-intervention session were compared with those post/during the intervention. The analysis in this section tests for an effect of session (before and after intervention) and its interaction with group (active or non-active groups). Here we report only interactions with either session or group, or session and group. Pairwise comparisons tested the difference between target types in both sessions, and within target types between sessions. As in Section 1, a Bonferroni adjusted alpha of .0125 was used (.05 / 9). These analyses test 1) if performance changes across sessions and 2) whether any benefits of that improvement can be isolated to active or non-active iterations of the intervention. We are primarily going to concern ourselves with the behavioural data (see Figure 14), though for completeness, tables of the same interactions are reported for the eye movement measures outlined in Section 1.

3.3.3.1 Working memory training (WMT) – Error rates

The main effect of Session approached but did not reach significance (F (1, 16) = 4.003, p = .062, η^2_G = .015). More errors made before the intervention (8.91%) than after it (6.81%). All other main effects and interactions failed to reach significance (all F < 1.631).

3.3.3.2 WMT – RTs

The main effect of Session approached but did not reach significance (F (1, 16) = 3.407, p = .084, η^2_G = .022), with longer RTs before the intervention (2503 ms) than after it (2241 ms). The interaction between Target and Session was significant (F (2, 32) = 4.483, p >.001, η^2_G = .043). In both sessions target absent RTs were longer than either target present RTs (all p values < .001), with no difference between target present trial types. No target types significantly reduced between the first and second session (all p > .047). No other main effect or interactions reached significance (all F values < 1.795).

3.3.3.3 tDCS – Error rates

The interaction between session, target and block approached but did not reach significance ($F (12, 216) = 1.623$, $p = .087$, $\eta^2_G = .020$). All other main effects and interactions failed to reach significance (all $F < 1.623$).

3.3.3.4 tDCS – RTs

The main effect of session was significant ($F (1, 18) = 11.650$, $p = .003$, $\eta^2_G = .050$), with longer RTs before the intervention (2503ms) than after it (2241ms). The interaction between target and session was significant ($F (12, 192) = 7.121$, $p =.001$, $\eta^2_G = .043$. RTs were significantly greater in target absent when compared to both target present trials in both the pre-intervention session (both $p < .001$) and post-intervention session (both $p < .001$). Target present trials were not significantly different in either session (both $P > .1$). Target absent trials were significantly shorter in the post-intervention session compared to the pre-intervention session ($p = .002$), but no other comparisons were significant. No other main effect or interactions reached significance (all F values < 1.795).

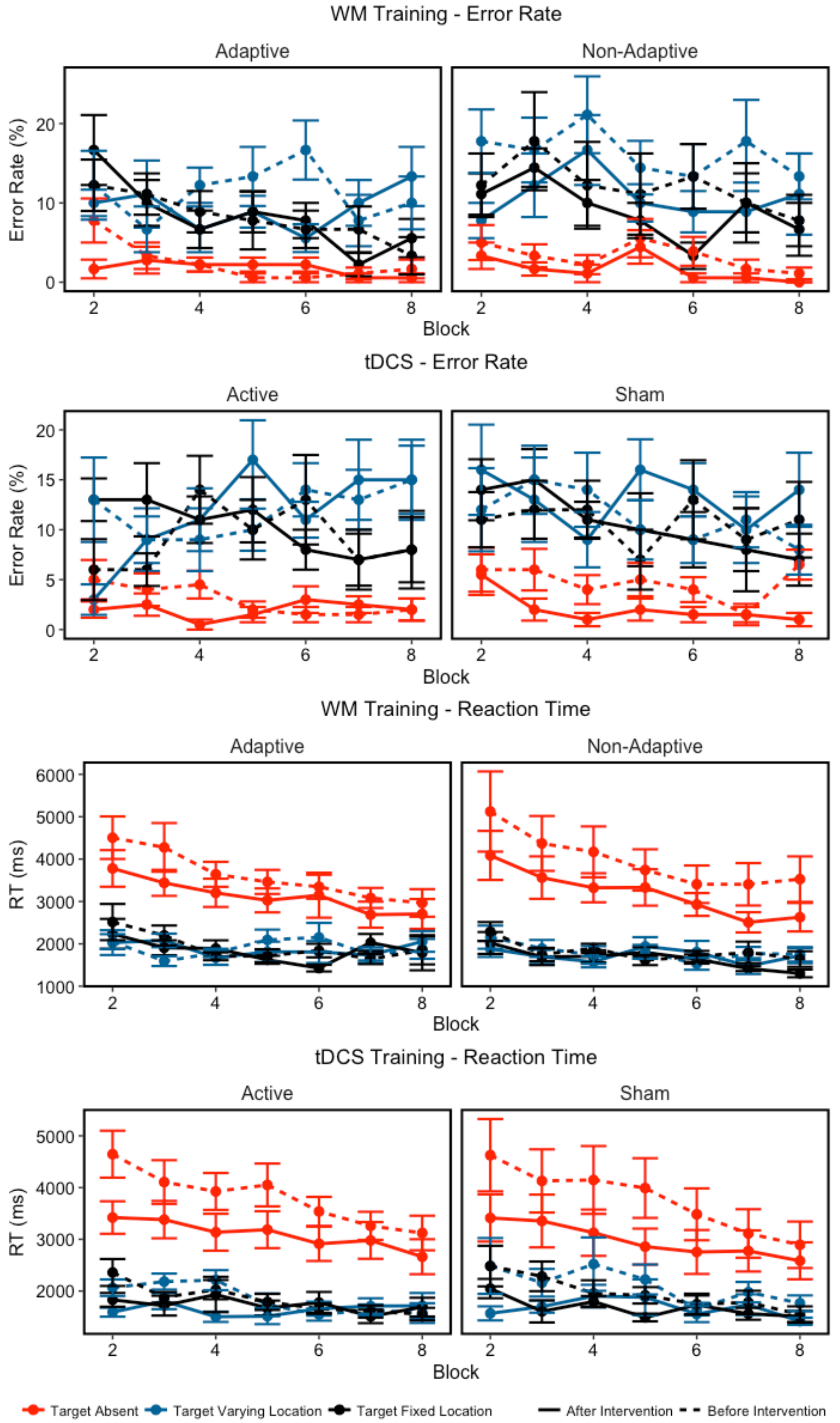

Figure 14. Error rates and RTs between Session, in WM training and tDCS interventions

Overall, performance was more accurate (though only in the WM intervention) and faster RTs post the intervention than before. On neither accuracy or RT, however, was there any interaction involving the interaction group itself. Completing the active or sham versions of the intervention had no impact on behavioural performance in the second session.

3.3.3.5 Eye movement measures

For the sake of completeness, the same analyses were conducted on the eye movement measures (see Tables 3 [WM training group] and 4 [tDCS group]).

Table 3. Eye movement measures in WM training group across Session

Measure	Main effect/interaction	Degrees of Freedom	*F*	*p*	η^2_G
Mean fixation duration	Session	1, 16	5.072	.039	.006
	Session/Group	1, 16	.499	.383	<.001
	Session/Group/Target	2, 32	.950	.398	.001
	Session/Group/Block	6, 96	.667	.676	.001
	Session/Group/Target/Block	12, 192	2.204	.013	.008
No. of fixations	Session	1, 16	4.442	.051	.023
	Session/Group	1, 16	.113	.742	<.001
	Session/Group/Target	2, 32	.130	.879	.001
	Session/Group/Block	6, 96	1.502	.186	.004
	Session/Group/Target/Block	12, 192	.575	.861	.002
Time to fixate	Session	1, 16	1.335	.265	.006
	Session/Group	1, 16	.102	.754	<.001
	Session/Group/Target	1, 16	.070	.794	<.001
	Session/Group/Block	6, 96	2.286	.042	.023
	Session/Group/Target/Block	6, 96	1.601	.155	.011
Verification time	Session	1, 16	1.357	.261	.008
	Session/Group	1, 16	.047	.832	<.001
	Session/Group/Target	1, 16	.239	.632	.001
	Session/Group/Block	6, 96	.707	.167	.014
	Session/Group/Target/Block	6, 96	.561	.761	.003

Table 4. Eye movement measures in tDCS group across Session

Measure	Main effect/interaction	Degrees of Freedom	*F*	*p*	η^2_G
Mean fixation duration	Session	1, 18	4.385	.051	.006
	Session/Group	1, 18	.256	.619	<.001
	Session/Group/Target	2, 36	.973	.388	.001
	Session/Group/Block	6, 108	.855	.531	.002
	Session/Group/Target/Block	12, 216	.935	.513	.004
No. of fixations	Session	1, 18	13.262	.002	.049
	Session/Group	1, 18	.378	.546	.001
	Session/Group/Target	2, 36	.072	.93	<.001
	Session/Group/Block	6, 108	.594	.734	.001
	Session/Group/Target/Block	12, 216	.628	.817	.002
Time to fixate	Session	1, 18	7.656	.013	.033
	Session/Group	1, 18	1.494	.237	.006
	Session/Group/Target	1, 18	.059	.811	<.001
	Session/Group/Block	6, 108	.995	.433	.009
	Session/Group/Target/Block	6, 108	.575	.749	.004
Verification time	Session	1, 18	4.394	.051	.027
	Session/Group	1, 18	.238	.632	.002
	Session/Group/Target	1, 18	.140	.712	<.001
	Session/Group/Block	6, 108	.683	.664	.005
	Session/Group/Target/Block	6, 108	1.319	.255	.006

Table 5. WM differences between Group and Session

Cognitive faculty	Measure	Main effect/ Interaction	Degrees of Freedom	*F*	*p*	η^2_G
WM Training						
Verbal WM	Max. Digit	Session	1, 16	12.800	.003*	.037
		Group	1, 16	.162	.693	.009
		Interaction	1, 16	3.200	.093	.009
Visuospatial WM	Accuracy	Session	1, 16	4.696	.046*	.055
		Group	1, 16	.217	.647	.011
		Interaction	1, 16	.010	.923	<.001
	RT	Session	1, 16	4.766	.044*	.044
		Group	1, 16	1.044	.322	.052
		Interaction	1, 16	.208	.654	.002
tDCS						
Verbal WM	Max. Digit	Session	1, 16	4.712	.045*	.087
		Group	1, 16	1.686	.212	.067
		Interaction	1, 16	.0210	.887	<.001
Visuospatial WM	Accuracy	Session	1, 18	11.806	.003*	.118
		Group	1, 18	.063	.804	.003
		Interaction	1, 18	2.541	.128	.028
	RT	Session	1, 18	24.150	<.001*	.120
		Group	1, 18	.0850	.774	.004
		Interaction	1, 18	1.175	.293	.007

3.3.4 Section 4: Group WM capacity differences between sessions

The performance of WM tasks (the CDT and the BDS) were analysed across interventions (WM training / tDCS) and between groups (active or sham) prior to and following the intervention (Session). The main effects and interactions of these analyses are shown (see Table 5, Figure 15). Two participants' data from the BDS became corrupted in the tDCS group, and which were not included in the analyses.

The results in Table 5 revealed that in all measures there was a significant main effect of Session in both WM and tDCS groups. With the exception of verbal WM in participants completing the tDCS intervention, the change in session marked a significant improvement in WM. In no case did the interaction between Session and Group reach significance. It was the case that there was a trend to an interaction in the case of verbal WM which benefitted the active WM training group over the non-active group (see Figure 15). Therefore, while the impact of WM training improved verbal WM, it did not improve visuospatial WM.

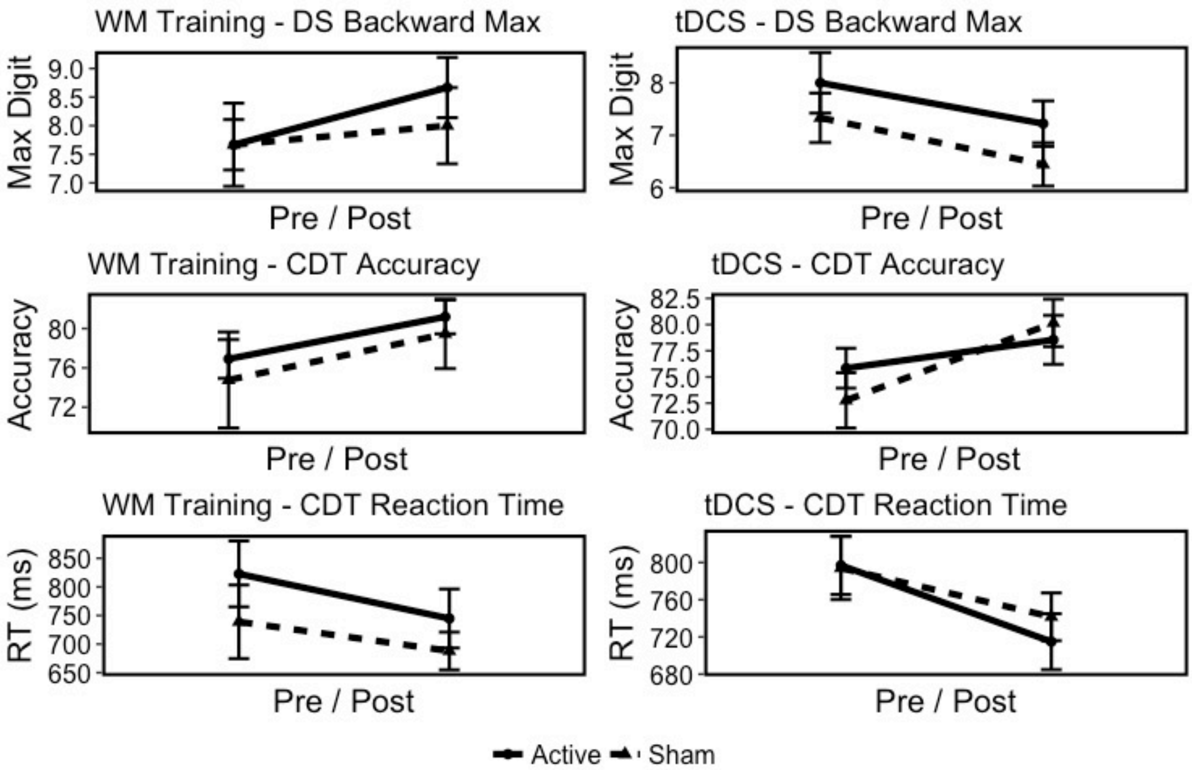

Figure 15. Change in WM between Group and Session

3.4 Discussion

Our first aim was to replicate the findings observed in the RSST from Tew et al (in prep, Experiment 3) when fixing targets to scenes and locations within scenes. Our second aim was to explore if a relationship between task performance in the RSST and WM might emerge if participants were not also exposed to the randomised condition. A third aim was to see if further evidence for a role of WM in performance on the RSST might be found by increasing WM capacity through training or tDCS.

With respect to the first aim, performance at baseline replicated our previous findings in relation to participants treating targets appearing in fixed locations differently from those appearing in varying locations. The replication in findings holds for both behavioural and eye movement measures.

With respect to the second aim, participant’s not being exposed to a randomised condition of the RSST allowed a clear relationship between performance change over blocks and visuospatial WM to emerge. It is likely that higher visuospatial WM speeds learning early in the task. The influence of attention that emerged in Experiment 3 of Tew et al (in prep) was not found in the present study, which is unsurprising as the influence of the alerting network upon performance was only found in the randomised route condition. The findings regarding the attentional networks tested (orienting, alerting and executive control) are replicated from Experiment 3 in Tew et al earlier study.

With respect to the third aim, we can find no evidence that efforts made to increase WM improved performance in the RSST. This is despite evidence of a positive effect of WM training on verbal WM itself. The absence of any influence of intervention on task performance is in striking contrast to the effect of overall practice on performance. There was evidence of speeded and more accurate decisions being made post-intervention than prior to it. The importance of finding a practice effect over sessions is that it shows task performance had not reached an asymptote at the end of the baseline. While performance gains could still be achieved by practice, no specific gains were made by increasing verbal WM. In hindsight, the failure to find an influence of improved verbal WM on target detection in the RSST is easy to explain. Only visuospatial WM was a significant predictor of performance change over blocks in the baseline phase.

An earlier study using the adaptive n-back training task did show improvement in visuospatial WM (see Owens et al, 2013). No effect was found in the present study despite more training days (15 days compared with 8 days). The difference between the studies is likely to be that Owen et al tested students suffering from dysphoria (who were theorised to have diminished WM capacity to begin with). It is then possible that the adaptive dual n-back training task may not improve visuospatial WM in the typical populations.

In conclusion, the present study has confirmed that participants can use scenes to predict target presence and this ability changes the number of fixations made when determining target absence and the time spent verifying targets. The ability to use scenes as cues to forthcoming targets is influenced by visuospatial WM, at least early in learning. Attempts to actively intervene to improve performance further were unsuccessful despite a general trend for search to improve from baseline to post intervention phases.

Chapter 4 The effect of increasing state anxiety on target search in repeated routes

Prepared for publication: Tew, O., Godwin, H. J., Garner, M., Hadwin, J. A., Liversedge., S. P. & Donnelly, N. *Increased state anxiety impacts visual search when learning routes.*

4.1 Introduction

Anxiety falls into two key areas within psychology: that of the description of the automatic allocation of cognitive resources due to the presence of an unpleasant stimulus (usually resulting in improved detection of that particular threat) or the tendency that an individual has to symptoms of anxiety, usually in a scenario in which the individual is not in clear and present danger. However, the extent to which situational (state) anxiety affects individuals completing potentially hazardous tasks has not been fully explored, particularly while learning a new environment (for example, police officers, soldiers) or completing a computer-based task that involves consistent vigilance (x-ray scanning, radar operators, CCTV monitors). While an individual's disposition towards anxiety (as a trait) can impair task performance (unless that task is searching for potentially threatening targets), the question of how an active state of anxiety affects search processes in a simulated environment has not been investigated. Additionally, while error rates or the time to complete a task are established measures of search performance, the effect of a state of anxiety upon the cognitive processes underpinning visual search and associated decision making has also not been investigated previously. Such questions are of paramount importance both within the fields of anxiety and visual search, as well as for the individuals that complete these searches in dangerous environments.

Anxiety has been shown to provide an advantage in the detection of angry faces (Matsumoto, 2010), and with regard to specific individuals with specific phobias, the presence of an anxious stimulus is detected faster (e.g. spider stimuli for arachnophobics; Flykt & Caldara, 2006; Soares, Esteves, Lundqvist, & Öhman, 2009). However, the advantage that anxiety brings to faster responses is usually only applicable when the targets are in some way negative or otherwise anxiety provoking. Indeed, on some occasions the presence of negative words or anxious scenarios actually will impair performance rather than improving it

(Derakshan & Koster, 2010; Murray & Janelle, 2003; Rinck, Becker, Kellermann & Roth, 2003).

An individual's "baseline" measure of anxiety can be taken at any time without a stimulus present, for example using the state and trait anxiety inventory scales (or STAI, Spielberger et al., 1983), which evaluate either the current level of anxiety an individual is experiencing (state), or how prone they are to those symptoms (trait). This and similar measures of anxiety have been used to rate individuals as "high-anxious", "low-anxious" or similar, and from there it is a simple process to establish the extent that an individual's propensity to anxiety can impact their cognitive behaviour (MacLeod & Donnellan, 1993; Murray & Janelle, 2003; Rinck, Becker, Kellermann, & Roth, 2003).

Anxiety can also be described in cognitive terms as a processing load on both working memory (processing efficiency theory, PET, Eysenck & Calvo, 1992) and attention resources (attentional control theory, ACT, Eysenck et al, 2007). In such models, the presence of a stimulus that triggers concern diverts attention from the task(s) at hand, with the result of reducing the efficiency on those tasks, and allocating resources to be aware of the threatening stimulus. Numerous experiments have managed to achieve an induction of stress or anxiety artificially, to better explore the effect of a state of anxiety ("stress") upon an individual in comparison to performance in a non-anxious state. The overall aim of these experiments, generally, is to explore how a threatening stimulus can affect cognitive behavior in a controlled environment, for example through the threat of electric shock (Lavric, Rippon & Gray, 2003; Shackman et al, 2006), through instruction during competition conditions (Murray & Janelle, 2003) and even unsolvable anagrams (Pomerleau, Turk & Fertig, 1984).

Another method of reliably inducing a mild state of anxiety is via the inhalation of 7.5% CO_2 via an oro-nasal mask for a short period of time (Attwood, Penton-Voak, Burton & Munafò, 2013; Easey et al., 2017; Garner et al., 2011; 2012; Hou et al., 2015). Via the inhalation task, it has been established that induced anxiety can increase the reaction times (RTs) of responses during a high load verbal working memory (WM) task (Hou et al., 2015), and impair the ability to correctly match audio and visual stimuli (Attwood, Penton-Voak, Burton & Munafò, 2013; Easey et al., 2017). It has also been established that various attentional networks (the orienting and alerting networks specifically) are influenced by induced anxiety, and that for individuals who already have high levels of trait anxiety, the negative effects of anxiety may increase relatively (Garner, Attwood, Baldwin, & Munafò, 2012).

While investigations into the effect of state anxiety has been explored in a number of directions (i.e. within cognitive behaviours) there is considerably less research that have addressed the question either within visual search, or utilizing memory for earlier scenes (e.g. Tew et al., in prep). Utilizing earlier memories for search is a cognitive activity that is in almost constant use, but the question of how that performance is influenced, or the memories successfully re-accessed in future searches, while the individual is in a state of anxiety, has not been answered. We have utilized a search task that facilitates strong learning effects over time (shortening of error rates, RTs, time to find & fixate targets, etc.) while completing the 7.5% CO_2 inhalation task in order to test these learning effects in a controlled state of anxiety. It is possible that these learning effects could be modulated by individual differences in cognitive resources (e.g. attentional networks [Fan et al., 2002], spatial or verbal WM), which may influence search and learning processing. Alternatively, differences in the propensity towards anxiety (i.e. trait), cognitive failures or depression may also reflect differences in participants' ability to use forthcoming scenes to predict probable target locations, particularly when in a state of anxiety. Therefore, in addition to assessing the effects of learning on both accuracy and RTs, we have investigated the cognitive functions underpinning search in repeated routes using eye movements, and taken steps to investigate the influence of innate cognitive (spatial/verbal WM, attentional networks) or personality (anxiety, depression, etc.) factors in learning from the environment while searching in a state of anxiety.

The aim of this experiment was to ascertain whether completing the RSST in a state of anxiety, which would be measured by both assessment scales and increases to heart-rate and blood pressure, would have any effect on search efficiency or eye movements measures supporting it (e.g. time to fixate and verify targets). In order to test this all participants completed the task twice, once while breathing in regular air and once while breathing in a mixture containing 7.5% CO_2, which has previously been shown to increase levels of anxiety in numerous studies.

To remain consistent with our results from earlier studies (Tew et al., in prep), the same stimuli in Experiment 3 (street routes with targets deployed) were used. In these stimuli, targets (tools) were either not present in individual scene identities (target absent scenes), were consistently present in scenes but in varying positions (varying target location scenes) or were consistently present in the same location (fixed location scenes). These scenes allow for three clear rules to be learned to ensure efficient search: some scenes never contain targets, the rest always contain targets, some of which always appear in the same parts of particular scenes. Targets appeared in pseudorandomised locations within the scenes (controlled for naturalistic position, but chosen by a randomised method).

It has been shown in earlier studies (Garner et al, 2011; 2012) that the inhalation of 7.5% CO_2 leads to several physiological indicators of a state of anxiety such as increased heart rate and blood pressure, as well as higher levels of reported anxiety, worry, lower levels of happiness, alertness, etc. We predict similar results to appear with our sample of participants. We hypothesized that while the learning effects demonstrated in an earlier study using the repeated scenes search task (Tew et al., in prep) would appear, there would be a reduction in performance benefit following repeated blocks of scenes in the 7.5% CO_2 inhalation condition (i.e. the degree of benefit will be decreased in the 7.5% CO_2 condition). These effects include reductions in error rates, RTs, and eye movements. Furthermore, we predict that there may be initially poorer performance in error rates, RTs and eye movement measures (longer search times, more errors, longer time to fixate and verify targets, longer fixation durations, etc.) that appear as participants begin to complete the task in a state of anxiety, caused by the 7.5% CO_2 condition. Consideration of individual differences in compensating against the effects of induced anxiety are also discussed using signal detection theory measures.

4.2 Method

4.2.1 Screening

Adult participants were invited through study advertisements to take part in a preliminary screen to take part in the study. Ninety-five adults replied to the advertisement and 71 were not able to take part in the CO_2 challenge if they reported being on long term medication (N = 8), were diagnosed with existing psychiatric disorders or symptoms of mild anxiety (N = 14), if visual acuity was < 1.0/they wore glasses/eye tracking calibration was out of limits (N = 14), if resting heart-rate was > 90BPM or blood pressure was > 140/90 (Systolic/Diastolic) (N = 20), if they were asthmatic/long-term smokers or had taken recreational drugs in the last year (N = 8). In addition, N = 7 individuals opted not to take part in the study after receiving further detail. A further N = 8 started the CO_2 challenge but stopped almost immediately reporting that they found it too intense, difficult, or otherwise did not wish to continue.

4.2.2 Participants

Sixteen adults (mean age = 22.50, SD: 3.58, range = 18-29, 6 female) took part in the study. Participants were compensated for their time either with course credits (equivalent to two hours of research participation) or with a monetary payment (£12.00).

4.2.3 The Repeated Scenes Search Task (RSST)

The repeated scenes search task (RSST) represents a learning paradigm made up of a series of 20 photographs that are presented sequentially to depict a walk through a suburban neighbourhood. There were two route versions (A and B) and to allow participants to become familiar with both routes they viewed each route 8 times (making up 8 experimental blocks). For each photograph participants were asked to make a decision about whether a target (i.e., a hand tool) was present or absent (and decisions were indicated by a button press, with audio feedback). To allow participants to become familiar with the route, targets were always consistently present or absent across scenes. For each route targets were present in 10 of the 20 scenes (i.e., 50%). In addition, in half of the target present trials, targets were presented in a fixed location for 5 scenes and in a varying location otherwise. Targets were present in naturalistic locations within the scene (i.e. in locations where tools could be conceivably left).

The familiarity and consistency of the search was designed to facilitate route learning across experimental block. Learning was measured in terms of behaviour (i.e., reduced reaction times and errors across experimental blocks) and eye movements (i.e., a reduced number of saccades and fixations and shorter saccade latencies to fixate targets, as well as shorter fixation durations) across experimental blocks.

4.2.4 Experimental conditions

Participants completed the repeated scenes search task twice (once for each route) in a single session, and across two experimental conditions - either with a 7.5% CO_2 mixture or with regular air. For both conditions, participants wore an oro-nasal facemask connected to a BOC cylinder. The cylinders contained 7.5% CO_2/21%O_2/ N_2 balance, pressure 200bar. Experimental conditions were counterbalanced with route across participants (making four possible task orders).

4.2.5 Individual differences measures

4.2.5.1 Working memory and attentional networks

Participants completed a number of experimental tasks and self-reported questionnaires to assess individual differences in cognitive performance[6]. Verbal WM was measured using a backward digit span (BDS) test from the WM index of the Wechsler Adult Intelligence Scales (Wechsler, 2008). The change detection task (CDT) was used to measure spatial WM task (see Owens, Koster & Derakshan, 2013). The CDT presents two images to either side of the visual field for 100ms, removed briefly (900ms) and then presented again for a longer period of time (2000ms). Participants are cued to one of the locations prior to the first presentation by an arrow (presented for 700ms) and asked to judge whether the picture in the second presentation was the same as in the first. The task generates accuracy and response time (RT) indices of spatial WM efficiency.

The control of attentional networks was measured via self-report (ACS & CFQ) and using the Attentional Network Test (ANT; see Fan, et al., 2002). The ANT asks participants to focus on a central fixation point and a target arrow appears either above or below pointing left or right. Targets were presented until response. The target is flanked by distractor arrows which may be pointing in the same (congruent) or opposite (incongruent) direction. The target location (either above or below the fixation point) may be cued (via a ***** presentation (100 ms) or may simply appear (no cue). In some trials both locations may be cued prior to the target and distractors appearing (double cue). The time to respond to the target is used to generate individual differences with respect to orienting (RT in the no cued trials minus the cued trials), alerting (no cued trials minus the double cue) and executive control (incongruent minus congruent trials) networks.

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[6] In Chapter 2 of this thesis a 3-step-n-back task was used to assess visuospatial and verbal WM. However, as this task is conceptually very similar to the adaptive dual-n-back training program, two sufficiently different tasks that assess the same cognitive resources were used both here and in Chapter 3.

4.2.5.2 Questionnaires

We measured participant symptoms of trait anxiety using the State-trait anxiety inventory (STAI, Spielberger, et al., 1983). The trait scale has 20 items relating to how anxious participants feel across a range of situations. Responses are given on a 4 point likert scale to reflect the extent to which each behaviour that generates a score range from 20 to 80, with higher scores reflecting increased anxious affect. The STAI has been shown to have good reliability (Barnes, Harp, & Jung, 2002). The study also measured participants' intolerance of uncertainty (IUS-12, Carleton, Norton and Asmundson, 2007), a construct associated with trait anxiety. This measure includes 12 statements which are scored between 1 ("Not at all characteristic of me") and 5 ("Entirely characteristic of me"), yielding a score between 12 and 60, with higher scores indicating a greater intolerance of uncertain events.

We measured depression symptoms using the depression subscale of the Hospital Anxiety and Depression Subscale (HADS; Zigmond & Snaith, 1983). This scale includes 7 items and participants are asked to indicate where they feel themselves to be between statements (e.g. "*I still enjoy the things I used to enjoy*") that are ranked between 0 ("*Definitely as much*") and 3 ("*Hardly at all*") for each to generate a score between 0 and 21 (with higher scores indicating elevated symptoms). Participants were also asked to complete two measures of self-reported of attentional control; the attentional control scale (ACS) and the cognitive failures questionnaire (CFQ). The ACS includes 20 items that measure attentional focus and shifting (Derryberry & Reed, 2002). For each item participants are asked to indicate the extent to which they experience the behaviour from 1 (never) to 4 (always), to generate a possible score from 20 – 80 and where higher scores indicate greater attentional control. The 25 item CFQ considers the frequency of everyday cognitive failures (Broadbent, et al., 1982). For each item participants respond 0 (never) to 4 (very often) to generate a score from 0 to 100 and where higher scores indicate more cognitive failures.

4.2.5.3 Assessment of state anxiety

We used several indices to measure state anxiety at two time points and as participants progressed through the search (baseline, and following each experimental condition). These included (1) the state anxiety scale from the STAI (Spielberger, et al., 1983). In this scale, participants are asked to read 20 items reflecting how anxious they feel at that moment, which are scored in the same way as the trait scale above. In addition, at each time point participants completed (2) a visual analogue scale (VAS) to indicate how alert, happy, ability to concentrate, relaxed, worried and tired they felt at three different time points (once before and following each inhalation). Participants were asked to indicate the extent to which they felt each emotional/ mental state on a dotted line that generated a score from 0 ("*Not at all*") to 18 ("*Extremely")*. The VAS also contained a scale on alertness, happiness, concentration, state of relaxation, worry and tiredness, with an increased score indicating an increased measure of mood.

We also used (3) measures of autonomic arousal (systolic and diastolic blood pressure) as indices of current anxiety and where typical measurements are < 120 and < 80 respectively (and respective measures of > 140 and > 90 are considered to be high). In addition, heart rate was used as a measure that was recorded prior to the inhalation sessions and following both. Differences in both heart rate and blood pressure have been used to provide a physiological indicator of elevated levels of state anxiety (see Garner et al, 2011, 2012).

4.2.6 Procedure

4.2.6.1 Screening

Individuals who expressed an interest in the study were given an information sheet. This included a description of the experimental procedure and the potential risk of feelings of anxiety following the 7.5% CO_2 condition. If individuals still wanted to take part, then they were invited to a screening interview. The screening interview asked individuals to respond to numerous questions that asked for information relating to their mental health or close family history of numerous mood disorders (e.g. Generalised Anxiety Disorder, depression, etc.), which has been used in earlier uses of this paradigm (see Garner et al, 2011 & 2012). We also measured individuals' visual acuity (a minimum of 1.0 decimal VA at a distance of approximately 1m; using the Freiburg Visual Acuity Test (Bach, 1996), colour vision (see the City University Colour Vision Test, 1998), resting heart-rate and blood pressure. Additionally, individuals completed a 9-point calibration task to ensure that the eye-movements were recorded accurately during the inhalation periods. (Each calibration point had no higher error than 0.5° of visual angle).

4.2.6.2 Experimental task

Following heart and blood pressure measurements, we asked participants to complete the experimental measures of WM and the ANT, followed by the questionnaire measures. This order of the tasks was fixed across participants. Indicators of current mood and state anxiety measures (the VAS and STAI), along with heart rate and blood pressure were re-taken following each inhalation stages of the experiment. Participants were briefed again on the main experiment, and were told how to signal (i.e., knocking clearly on the desk top) if they did not wish to continue during the task.

Participants were then fitted with the oro-nasal mask and completed the repeated scenes search task (Route A or B) for the first condition air or CO_2. Following a mandatory ten-minute (minimum) break, participants were re-fitted with the oro-nasal mask and completed the alternative repeated scenes search route and for the second condition. Following a second ten-minute break, participants were debriefed on the nature of the experiment and were informally asked if they could identify which of the breathing conditions was the regular air and which was the 7.5% CO_2 mixture. All but one of the participants was able to correctly identify if it was the first or second session. Following the debrief participants completed the VAS and state-STAI questionnaires, and had heart-rate and blood pressure for the fourth and final time and to ensure that there were no residual effects of the 7.5% CO_2 inhalation. Participants were contacted the following day to check if the participant had experienced any side effects following the of CO_2 manipulation (a single complaint reported by several participants was of a mild headache that abated within a few hours).

The experimental procedure was approved by the University of Southampton Ethics and Research Governance Office and the Ministry of Defence Research Ethics Committee (MoDREC), and followed the conventions of the Declaration of Helsinki. Full written consent was obtained from each participant after an explanation of the experimental procedure was provided.

4.3 Results

4.3.1 Approach to analysis

Preliminary analysis assessed the CO_2 manipulation check. We used repeated measures ANOVAs to compare the physiological indices (i.e., systolic and diastolic blood pressure, heart rate) and questionnaire measures between three time periods (at baseline, following the CO_2 inhalation, following normal air inhalation, see Table 6). An impact of condition on indices of state anxiety would be evident in a main effect of time and with post-hoc comparisons indicating key differences following the CO_2 condition relative to the normal air inhalation and baseline measurements. Further analyses focused on learning in the repeated scenes task. With the exception of error rates, outliers (defined as >3SD from the mean) were removed prior to analyses (ranging from 1.5-2.6% of data per analysis). The focus of interest was on the impact of the experimental condition on the efficiency of search (i.e. error rates, RTs, the time to find and verify target identity, the length and number of fixations in trials), all of which are predicted to reduce over blocks as search becomes more efficient and where this change is most evident for targets presented in the same location. Error rates were further explored using signal detection measures to investigate whether the CO_2 inhalation reflected a different search strategy. Finally, in order to explore individual differences in anxiety and cognition, we explored the relationship between the signal detection criterion change over blocks in both the CO_2 and Air condition, allowing us to establish how participants are able to improve their decisions in a potentially anxious situation, but in which the trigger for anxiety is not instigated.

In all of the measures (error rates, RTs fixation durations, number of fixations, time to fixate and verify targets), and following from the methods and analyses of our earlier work (Tew et al., submitted, in prep) we predicted that there would be reductions with increases in experience with the route (blocks). Improvements would be observed both in search efficiency (behavioural measures) and cognitive processing involved in search (eye movements), as participants became more familiar with scenes and targets. We also predicted that there would be a significant impact on either search efficiency or cognitive processing when the route was completed in the CO_2 inhalation condition when compared to the air condition. It was predicted that initial performance would suffer from the influence of state anxiety, and that this could also interact with decrements in learning when compared to the air condition. This decrement could be potentially facilitated by factors in cognition (WM or strength in attentional networks) or by disposition towards anxiety or other psychological factors.

4.3.2 Manipulation check: self-reported state anxiety, blood pressure and heart rate

Table 6 shows self-reported data for all measures of trait and state anxiety and depression, and at all time points (baseline, post-CO_2 and post-air inhalations). These data were analysed independently across each time point. The main effect of time was significant for blood pressure (systolic, diastolic), heart rate, state anxiety and responses on the VAS (all scales excluding "Alertness") were significant (all Fs > 3.62 and all ps < .05). Post-hoc analyses revealed that systolic blood pressure, heart rate and state anxiety levels were significantly elevated following the CO_2 inhalation (with no significant difference between the baseline and air time recordings) and that levels of happiness, concentration and relaxation were significantly decreased following the CO_2 inhalation (with no significant difference between the other two time periods, see Table 6).

Table 6. Mean, standard deviation, and range for indices of self-reported and measured indices of state anxiety and mental functioning at baseline and post the CO2 and air inhalation experimental conditions

	Baseline		**Air**		**7.5% CO2**		
	Mean (SD)	**Range**	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	**ANOVA F (2, 30)**
Measured							
Systolic blood pressure	123.88 (13.32)	100-149	127.56 (11.08)	111-153	136.88[a] (13.37)	113-161	10.99, $p < .001$, $\eta^2_G = .116$
Diastolic blood pressure	71.63 (10.38)	53-97	74.13 (9.660)	56-93	78.19 (7.016)	62-89	3.856, $p = .032$, $\eta^2_G = .086$
Heart rate	67.31 (9.485)	53-96	67.31 (9.816)	51-93	78.13[a] (9.164)	63-94	10.58, $p < .001$, $\eta^2_G = .235$
Self-reported							
State anxiety (20-80)	28.88 (8.755)	20-50	28.69 (7.525)	20-47	40.63[a] (13.11)	21-70	15.75, $p < .001$, $\eta^2_G = .246$
VAS (0-180)							
Alert	105.69 (43.74)	33-168	105.75 (38.43)	23-167	95.31 (39.91)	18-164	1.379, $p = .267$, $\eta^2_G = .015$
Happy	122.13 (21.60)	88-145	116.93 (22.15)	51-135	75.53[a] (32.93)	3-114	17.62, $p < .001$, $\eta^2_G = .406$
Concentration	135.13 (30.80)	71-179	122.31 (27.96)	61-162	92.19[a] (38.33)	12-142	9.219, $p = .001$, $\eta^2_G = .245$
Relaxation	113.88 (33.51)	36-154	125.31 (28.17)	78-168	83.81[a] (42.35)	1-154	7.686, $p = .002$, $\eta^2_G = .209$
Worried	39.69 (35.72)	2-128	34.00 (31.93)	3-123	63.63 (42.97)	3-129	5.557, $p = .009$, $\eta^2_G = .113$
Tired	70.87 (44.94)	5-145	76.07 (47.38)	3-163	98.07 (40.36)	24-152	3.616, $p = .040$, $\eta^2_G = .071$

Within each measure (row), mean values with different superscripts (a, b, c) significantly differ from each other p's < .05)

Table 7. Correlation between anxiety measurements recorded at baseline

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Physiological measures										
1. Systolic pressure	--									
2. Diastolic pressure	.42	--								
3.Heart rate	.38	.15	--							
Visual analogue scale										
4. Alertness	.13	-.05	.03	--						
5. Happiness	-.13	-.09	-.01	-.40	--					
6. Concentration	-.06	$-.50^{*}$	.02	-.14	$.51^{*}$	--				
7. Relaxed	-.15	.16	-.38	.27	.10	-.12	--			
8. Worried	.28	.05	-.01	.15	$-.64^{**}$	$-.51^{*}$	-.47	--		
9.Tiredness	.16	.39	.30	<-.01	-.46	$-.75^{**}$	-.16	$.53^{*}$	--	
10. State anxiety	.31	.15	.08	.12	-.31	$-.69^{**}$	-.29	$.64^{**}$	$.58^{*}$	--

Table note: $^{\#}p < .10$, $^{*}p < 0.05$ level (2-tailed), $^{**}p < .01$.

Consideration of associations between objective and self-reported measures of state anxiety at baseline showed that several items correlated against each other. These are reported in Table 7. These indicate that rates of state anxiety were negatively correlated with the ability to concentrate and positively correlated with levels of worry and tiredness. In addition, the ability to concentrate was positively correlated with happiness and negatively with worry and tiredness. Diastolic blood pressure was negatively correlated with the ability to concentrate and close to significant-positively correlated with anxiety ($p = .051$).

4.3.3 The Repeated Scenes Search Task

The benefits of experience with the scenes (examining earlier target locations for new targets, for example) will only become evident when the scenes have been seen previously, the first block of data was excluded from data analysis. The data were analysed between 2 conditions (CO_2 and air) and across 7 blocks (2-8) by comparing indices of search performance on trial type (target present versus target absent trials) and secondly by comparing target category (fixed versus varying locations). The results for analyses on target type (present vs absent) are shown in Figure 16, and the analyses on target category (varying vs fixed locations) are shown in Figure 17. It was anticipated that learning would be reflected in performance increases across blocks (i.e. fewer error rates and fixations, shorter RTs and time to fixate and verify targets) and most evident for the fixed (versus random) target category. Any main or interaction effects associated with block were investigated using paired sample t-tests using comparing the values at blocks 2 and 8. When appropriate (i.e. when decrement over blocks was significant in all target categories), the differences between blocks 2 and 8 for target types/categories were compared, to establish the direction of the interaction. One participant was removed from the eye-tracking data due to a corrupted file. Two other participants were removed from the time to fixate and verify targets, as in at least one block there were not enough correct responses that also landed on the target (i.e. 1 or more).

4.3.3.1 Behavioural measures

4.3.3.1.1 Error rates

The main effect of trial type was statistically significant ($F(1,15) = 14.72$, $p = .002$, $\eta^2_G = .114$); error rates were lower on target absent (7.10%) compared with target present trials (14.91%). There were more errors made in the CO_2 (versus the air) condition (12.46% and 9.55%), but this difference did not reach statistical significance (F(1,15) = 3.16, p = .095, η^2_G = .017), In addition, there was a significant three-way interaction between condition, block and trial type (F(6,90) = 2.71, p = .018, η^2_G = .029). The data was split by condition (CO_2 /Air) to fully explore this interaction. During both CO_2 and the Air condition there was a main effect of trial type (F(1,15) = 5.013, p = .041, η^2_G = .081, F(1,15) = 21.474, p < .001, η^2_G = .166 respectively). The interaction between block and trial type was also significant in the air (but not the CO_2) condition (F(6,90) = 2.332, p = .039, η^2_G = .054), highlighting that errors trended towards decreasing between Blocks 2 and 8 in target absent trials in the air but not the CO_2 condition. There was no significant difference between the conditions at either block 2 or block 8, or between targets at either block 2 or 8. All other main and interaction effects were not significant (all Fs < 1.820 and ps >.05).

The error rates for target present trials were compared across target category (fixed versus random). The main effect of target category (fixed versus random) was significant (F (1, 15) = 8.206, p = .012, η^2_G = .016), revealing fewer error rates on fixed (12.87%) versus random (16.96%) targets. The interaction between condition and block approached significance (F (6, 90) = 2.20, p = .050, η^2_G = .024), indicating that error rates in target present trials were higher in the CO_2 condition, and decreased between blocks 2 and 8, however pairwise comparisons did not confirm this to be significant. The interaction between block and target category also approached statistical significance (F (6,90) = 1.98, p = .077, η^2_G = .025), showing that search for targets in fixed (versus varying) locations were linked to fewer errors in block 8 versus block 2 (p = .032). No other comparisons reached significance. All other main and interaction effects were not significant (all Fs < .70, ps >.65).

4.3.3.1.2 Reaction times (RTs)

The main effect of trial type was significant (F(1,15) = 91.83, p < .001, η^2_G = .35), indicating longer RTs for target absent (3318ms, SD = 1321) than target present trials (M = 1970 ms, SD = 653). The main effect of block was also significant (F(6,90) = 42.83, p < .001, η^2_G = .18), with RTs decreasing from 3452 ms in block 2 to 2125 ms in block 8. The interaction between trial type and block was also significant (F (6, 90) = 13.83, $p < .001$, $\eta^2_G = .06$). RTs fell significantly between blocks 2 and 8 and were significantly higher in block 2 than block 8 in both target types (*p*s for all comparisons < .001). Comparing the difference in RTs revealed that RTs in target absent trials reduced significantly more over blocks (*M* = 1126 ms, *SD* = 850) than trials with targets ($p < .001$). No other main or interaction effects were significant (all *F*s < 1.046, *p*s >.401).

Considering target category in target present trials, the main effect of block was significant (F (6,90) = 9.08, $p < .001$, $\eta^2_G = .08$), with RTs reducing from 2067 ms in block 2 to 1573 ms in block 8. In addition, the main effect of target approached significance ($F(6, 90) = 4.22$, $p = .058$, $\eta^2_G = .01$), highlighting targets in fixed locations were found faster (*M* = 1819 ms, *SD* = 614) than those in varying locations (*M* =1926 ms, *SD* = 635). No other main or interaction effects were significant (all *F*s < 1.138, *p*s >.303).

4.3.3.2 Eye movements

4.3.3.2.1 Mean fixation duration

The main effect of trial type was significant ($F(1,14) = 35.12$, $p < .001$, $\eta^2_G = .09$); fixation durations were longer on target absent (*M* = 218 ms, *SD* = 27.61) than target present trials (*M* = 201 ms, *SD* = 26.95). The main effect of block was significant (F(6,84) = 2.87, $p = .014$, $\eta^2_G = .02$), with fixations decreasing from 217 ms to 205 ms from block 2 to block 8. The main effect of condition was also significant ($F(1,14) = 5.27$, $p = .038$, $\eta^2_G = .013$), highlighting longer fixations in the CO_2 condition (*M* = 212 ms, *SD* = 29.09ms) than the Air condition (*M* 206 ms, *SD* = 27.64). No interactions were significant.

The same analyses were computed to explore the difference between searching for target category across blocks. There were no significant main effects or interactions (all *F*s < 2.369 and *p*s > .146).

4.3.3.2.2 Mean fixation count

There was a significant main effect of trial type ($F(1,14) = 87.05$, $p < .001$, $\eta^2_G = .50$); there were more fixations on target absent (*M* = 10.35, *SD* = 4.14) than target present trials (*M* = 4.88, *SD* = 1.37). The main effect of block was also significant (F (6, 84) = 37.76, $p < .001$, $\eta^2_G = .163$), indicating that there were fewer fixations in block 8 (*M* = 6.09, *SD* = 3.011) compared with block 2 (*M* = 9.713, *SD* = 5.414) The interaction between trial type and block was also significant (F (6, 84) = 20.01, $p < .001$, $\eta^2_G = .07$). Both target types reduced between blocks 2 and 8 and were significantly fewer in target present than absent trials at blocks 2 and 8 (all *p*s < .001). The fall in target absent fixations across blocks 2 to 8 was significantly greater than the fall in target present trials ($p < .001$).

Considering target category in target present trials. The main effect of block was significant (F (6, 84) = 6.38, $p < .001$, $\eta^2_G = .09$); the number of fixations decreased from block 2 (*M* = 5.058, *SD* = 1.502) to block 8 (*M* = 4.045, *SD*= 1.137). The interaction between block and target category was also significant (*F* (6, 84) = 2.308, $p = .041$, $\eta^2_G = .022$). The mean fixation count reduced for both target category over blocks 2 and 8 (both *p*s = .001). The reduction between targets in fixed location between blocks 2 and 8 approached significance ($p = .077$), but not in targets in varying locations. No other main effects or interactions were significant (all *F*s < .770 and *p*s > .395).

4.3.3.2.3 Time to fixate targets

We considered time taken to fixate the target in target present trials. The main effect of block was significant (F (6, 72) = 2.94, $p = .013$, $\eta^2_G = .04$), with time taken to fixate the target being significantly less for block 8 (*M* = 725 ms, *SD* = 257) compared with block 2 (*M* = 890 ms, *SD* = 355). No other main effects or interactions approached significance (all *F*s < 2.710).

4.3.3.2.4 Verification time

The time to verify targets following initial fixation was analysed. The main effect of block was significant ($F(6,72) = 5.17$, $p < .001$, $\eta^2_G = .08$), with times reducing over block (i.e., they were lower in block 8 (*M* = 679 ms, *SD* = 207) compared with block 2 (*M* = 893 ms, *SD* = 246)). The main effect of condition was also significant ($F(1,12) = 18.00$, $p= .001$, $\eta^2_G = .03$), with statistically significant differences in verification times in the CO_2 condition (*M* = 834 ms, *SD* = 284) compared with the air condition (*M* =744 ms, *SD* = 221). The main effect of target category and all interactions did not reach significance (all *F*s < 1.089).

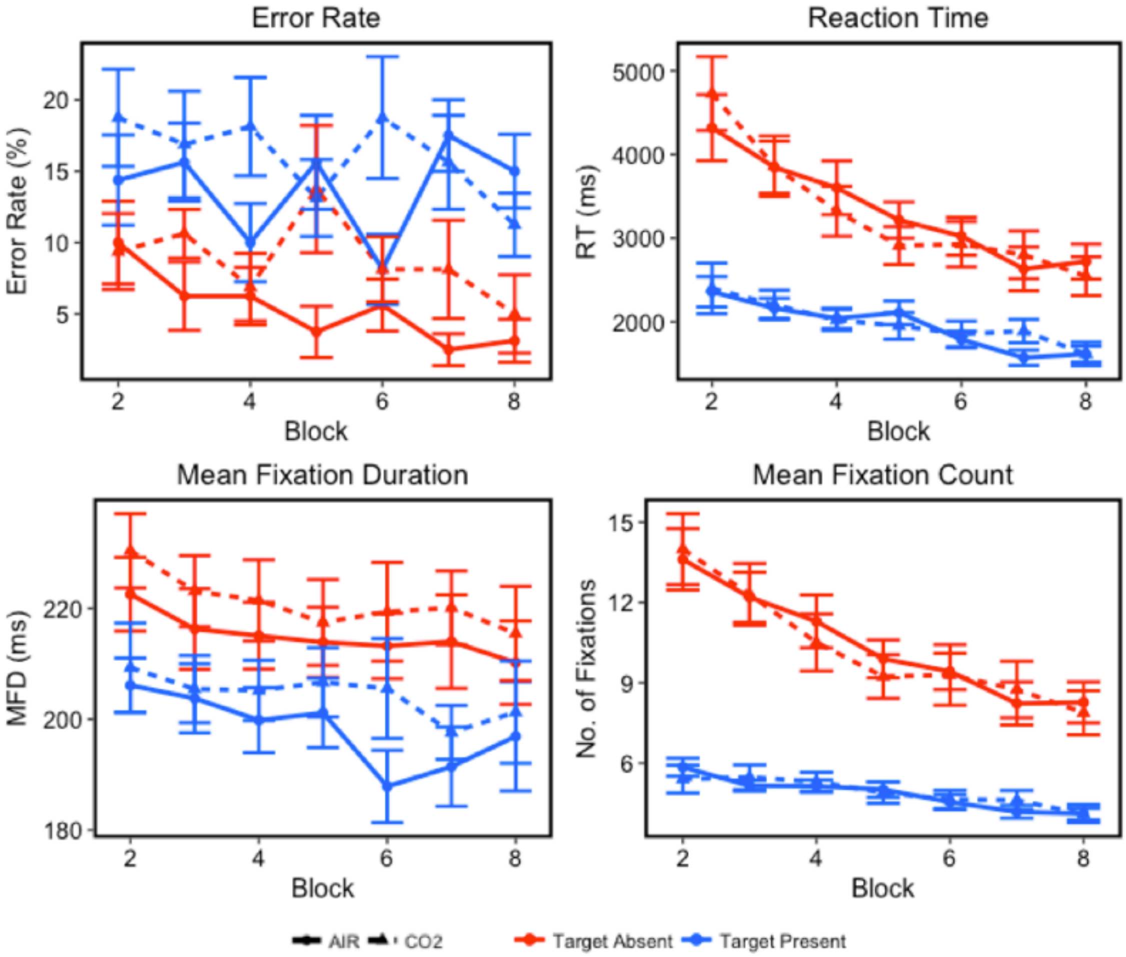

Figure 16. Graphs displaying data in analyses of Target type

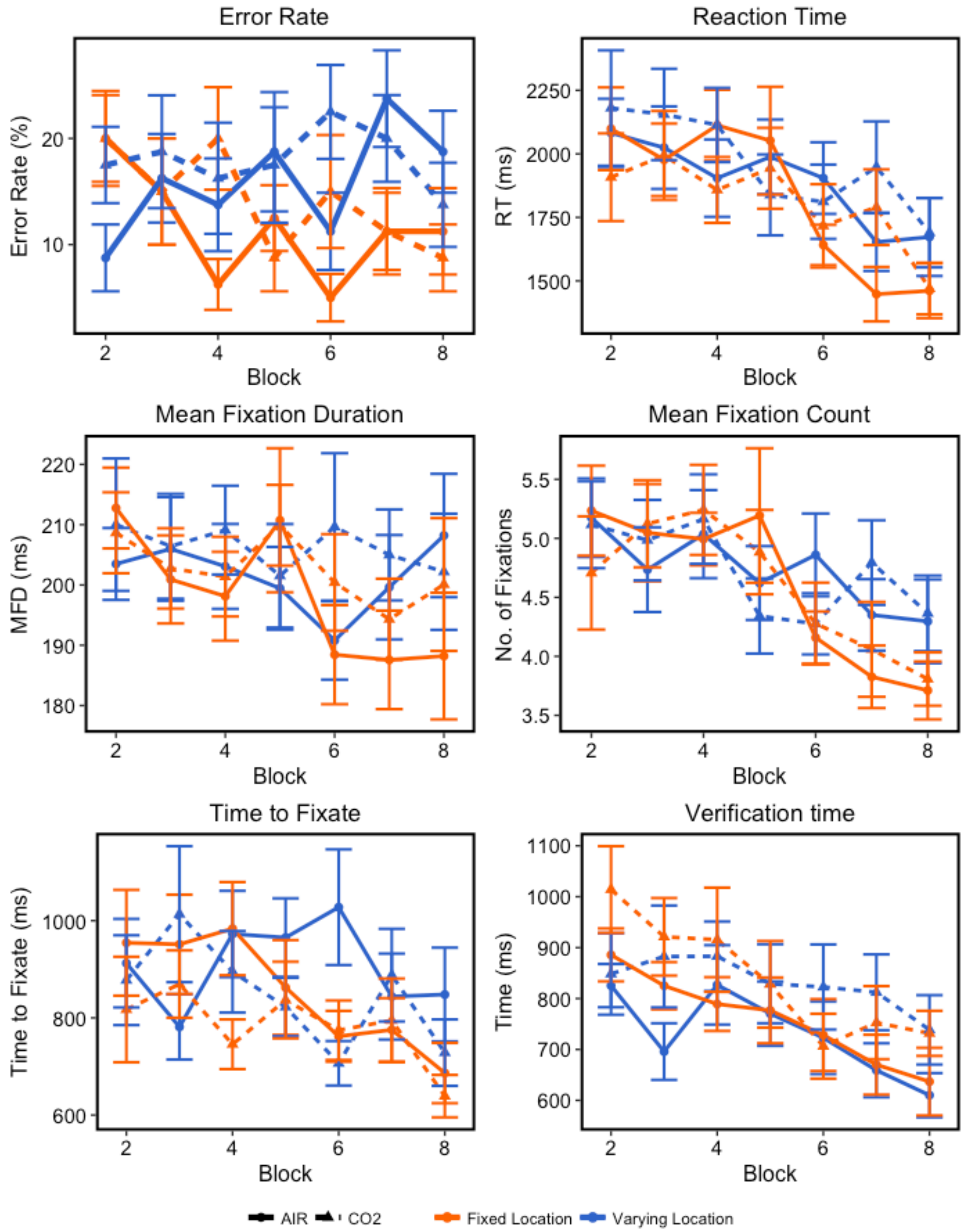

Figure 17. Graphs displaying data in analyses of Target category

4.3.4 Exploration of errors using signal detection analysis

The error analysis showed that errors decreased in absent trials, but only for the air condition. In contrast errors in target present trials remained stable across block. This result may reflect a shift in signal detection criterion (c) of what constituted a legitimate target and when it was present or absent. Within the framework of signal detection theory, this result can be described as the degree to which participants are prepared to respond positively to a potential signal, with a higher value of c determining a more conservative threshold (i.e. fewer false alarms, but potentially more misses). Another measurement in signal detection theory which is argued to reflect increased experience is the sensitivity index (d prime or d'), which reflects the difference between signal (response to target) and noise (background scenes or non-target objects) distributions, with d' increasing with increased experience of what a genuine target will be (Menneer, Donnelly, Godwin & Cave, 2010; Macmillan & Crelman, 2005).

We calculated the values of c and d' for each block and within each condition. These indices were explored using a repeated measures ANOVA between condition and across blocks to compare changes in decisions over blocks.

4.3.4.1 Sensitivity index (d')

There were no main or interaction effects of block or condition (Fs < .3 and ps > .1, see Figure 18a).

4.3.4.2 Signal detection criterion (c)

The main effect of both condition and block was not significant (Fs < 1 and ps > .1). The interaction between block and condition was significant ($F(6,90) = 2.52$, $p = .027$, $\eta^2_G = .05$, see Figure 18b). The result showed that while c remained stable in the CO_2 condition, it increased over blocks in the air condition - indicating some adjustment of the signal detection criterion reflected in a shift towards a more conservative decision-making process. Pairwise comparisons between values at block 2 and block 8 did not reveal any significant differences.

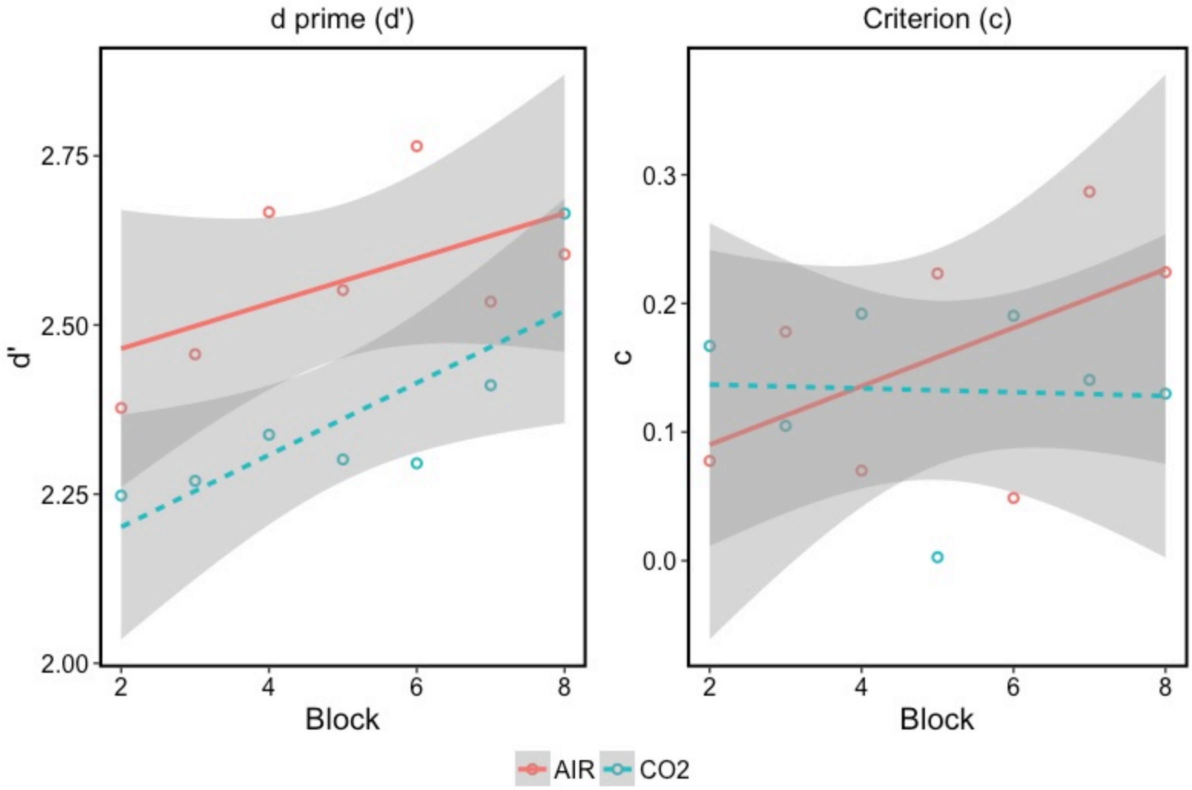

Figure 18. Graphs displaying data in signal detection analyses

4.3.5 Using signal detection to explore individual differences in anxiety and cognition with search

In order to explore the relationships between indices of anxiety and attention with performance in the search task we characterised the shift in the CO_2 and air inhalation conditions by fitting a linear slope using the signal detection criterion (c) across blocks. By subtracting the CO_2 slope from the air, we established a gradient of shift in criterion and where more positive values (increased differences) reflects increased signal detection criterion shift in the air relative to the CO_2 condition for each participant. see Figure 18). We explored associations between slopes and individual differences in attention and anxiety; see Table 8. This table shows that a smaller change in criterion between the CO_2 and air conditions was associated with increased negative affect and elements of attentional control (self-reported symptoms of trait anxiety, and increased cognitive failure; see Table 8 and Figure 19).

Table 8. Correlation between difference in c and battery of individual measures

	Diff. in c	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Working Memory													
1. Verbal WM	.18	--											
2. Visuospatial WM Accuracy	-.03	.12	--										
3. Visuospatial WM RT	-.13	-.19	-.33	--									
Attentional Networks													
4. Orienting	.34	-.15	-.13	-.16	--								
5. Alerting	-.72**	-.06	-.02	-.09	-.72**	--							
6. Executive Control	-.38	.19	-.06	.15	-.29	.37	--						
Questionnaire measures													
7. Trait Anxiety	-.52*	.04	.26	-.32	-.31	.69**	.23	--					
8. State Anxiety	-.66**	.22	-.13	.11	-.37	.62*	.64**	.62*	--				
9. ACS	.45#	.11	-.03	-.10	.37	-.53*	.09	-.68**	-.51*	--			
10. Depression	-.36	.23	-.08	-.04	-.46#	.39	.36	.35	.72**	-.45#	--		
11. CFQ	-.72**	.02	<.01	-.22	-.20	.61*	.15	.63**	.63**	-.57*	.44#	--	
12. IUS	-.41	-.04	.036	.063	-.11	.44#	.38	.62*	.57*	-.53*	.43#	.50*	--

Table note: #p < .10, *p < 0.05 level (2-tailed), **p < .01.

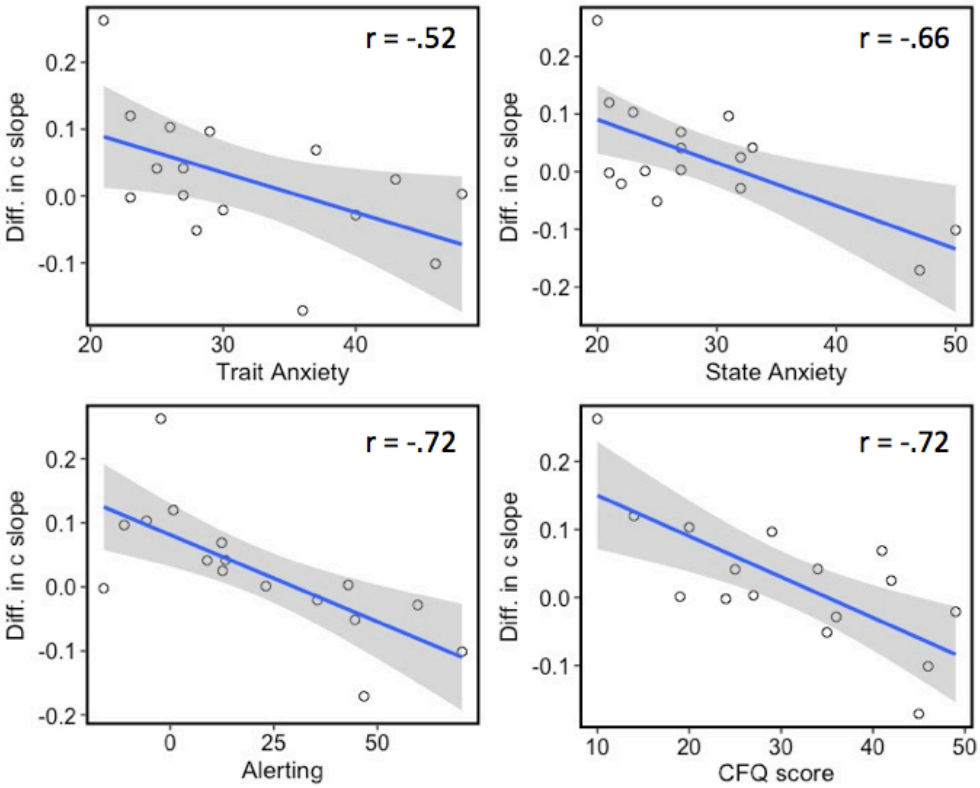

Figure 19. Correlations between difference in c and individual differences battery

4.4 Discussion

The primary aim of the experiment was to explore the effect of induced anxiety upon search for targets in repeated routes, and to establish if either behavioural or cognitive performance was affected. Investigation of the direct influence of anxiety upon search and learning processes in real-world environments has not yet been attempted prior to this experiment. The above aim was achieved, in that anxiety was considerably higher following the CO_2 inhalation, with participants exhibiting physiological symptoms of anxiety, as well as higher levels of self-reported anxiety, and with a distinctly different pattern of results found while participants completed the RSST in the CO_2 inhalation session.

The experiment replicated several findings that have been seen in earlier uses of this paradigm (Tew et al., in prep). Error rates differed based on target type, while RTs and both the durations and the number of fixations decreased with block, as did the time to fixate and verify targets. Accuracy was always higher in target absent trials, which had the greatest decrease in RT and number of fixations over blocks. Additionally, targets appearing within fixed locations were found faster than those in varying locations, although there was no difference in target category in the time to verify.

The inhalation of CO_2-enriched air uniquely affected a number of participant responses, beginning with a three-way interaction between condition, block and target type. Splitting the data across condition revealed that error rates in target absent trials fell over time, but only in the air condition, while those in the CO_2 condition did not fall, nor did target present trials. The decrement in these type of errors (false alarms) over block indicated that there may have been a shift in signal detection criterion that presented in the air condition, but not in the CO_2 condition. This supposition was confirmed by additional analysis.

The combined results of the signal detection measures analysis reveal two very important findings. First, in the presence of anxiety individuals do not adjust their decisions to avoid errors to the same extent as in a non-anxious state. Second, certain individuals are less likely to shift their decisions, or shift them to a smaller degree, even when completing search without induced anxiety. These are individuals with increased resources in the alerting network (indicating they respond quickly to sudden signals) or are predisposed to either anxious traits or cognitive failures. The adjustment in criterion can be understood from a perspective in prevalence, with individuals becoming calibrated to the frequency of targets (reducing fixation durations, number, decreasing requirement to fixate targets; Godwin, Menneer, Riggs, Cave & Donnelly, 2015; Tew et al, in prep).

Also, importantly, increased overall errors were made when completing the 7.5% CO_2 condition compared to the normal air condition. This result produced a small, but reliable, effect, and it should be noted that a high number of participants removed themselves from the study. As those participants had found that the task was too difficult to complete while breathing in the 7.5% CO_2-enriched gas, it may be considered that the final results only reflect participants who have a greater than average tolerance for anxiety. The finding of an increased error rate when completing the search task in the anxiety condition is consistent with earlier experiments in which forced choice decisions are not improved by the presence of anxiety (Attwood, Penton-Voak, Burton, & Munafò, 2013), or when accuracy is impaired by induced anxiety (Easey et al., 2017; Attwood, Penton-Voak, Burton & Munafò, 2013). The question of whether this finding is purely due to impaired decisions, or is related to visual cognition, can be further explored in the findings from the eye movement data.

Fixation durations were lengthened in the CO_2 condition relative to the air condition, in both target absent and target present trials. As this did not occur with either longer RTs overall, or a higher number of fixations, this reflects a different strategy in visual processing (rather than a general slowing of efficiency), with longer fixations being necessary to achieve the same standard of performance. Verification times were also extended in the CO_2 inhalation condition, although decreased at the same rate as those in the air condition. It can therefore be theorised that heightened levels of anxiety brought on by the inhalation of CO_2 affected participant's ability to search, in both the learning and recognition of targets. The increased verification times strongly imply that the decision of what does and doesn't constitute a correct target is significantly hindered by an anxious state. Earlier research in this field has also established that both the threat of an anxiety provoking stimulus, as well as its presence, can affect the deployment of eye movements (Gerdes, Alpers & Pauli, 2008). Added to the longer fixation durations observed in both the target present and absent trials, it would appear that participants are less confident in their search ability, requiring longer time to examine the particular structures of the scene and targets before responding, although this does not contribute to either longer searches or increased fixations overall.

These findings all show a change in the way participants examine the scenes and targets when in the CO_2 relative to the air condition. We also suspected that the decrease in false alarms may have been a sign of shifting criterion that was only present in the air condition, which we then confirmed. When combining these findings, an interesting new account of how state anxiety can affect search emerges. In order to search environments effectively, legitimate targets must be detected, and a natural by-product of search is the false alarm, in which objects thought to be targets are examined. In a real-world search task, picking up and examining an object before deciding it is not the target would constitute a false alarm. Learning what does *not* constitute a target acts in line with signal detection theory, in which the criterion is shifted in order to reduce false alarms. It would appear that while completing the 7.5% CO_2 inhalation (i.e. in a scenario that triggers a mild state of anxiety) the ability to learn from experience is compromised, with a particular reference to target identities. Targets are as likely to be missed in future trials even when they have been fixated for longer, and false alarms do not decrease significantly over the course of the task. In addition, longer fixation durations do not occur with either a higher proportion of correct responses, or any indication of improved search (shorter RTs, fewer total fixations, shorter time to fixate targets).

The results suggest a strong effect of anxiety upon performance on the entire group (increased error rates, longer fixation durations and verification times). This was followed by further analysis into how individual differences in anxiety (and other personality traits) and cognitive resources (WM and attentional network strength) may influence learning of targets (i.e. change in criterion) across the two conditions. These findings revealed that participants with high levels of trait or state (measured at baseline) anxiety were less likely to increase their criterion in the air condition, and as such could be described as learning at an increasingly slower rate from the scenes presented. The alerting network was also highly correlated with decreased change in criterion, which may be due to the fact that the alerting network responds quickly to perceived targets, and therefore these individuals may be significantly more likely to make false alarms.

The results from earlier studies have provided a variety of potential responses to induced anxiety, but often is either increased (Matsumoto, 2010; Flykt & Caldara, 2006; Soares, Esteves, Lundqvist, & Öhman, 2009) or decreased (Rinck, Becker, Kellermann & Roth, 2003; Derakshan & Koster, 2010) RTs, depending on whether or not the target being searched is associated with threat. These findings fall into the cognitive models of anxiety (e.g. processing efficiency theory: PET, Eysenck & Calvo, 1992; attentional control theory: ACT, Eysenck, Derakshan, Santos & Calvo, 2007) that describe the shortening of cognitive/attentional resources in the presence or the possibility of threatening stimuli, with the outcome that the other activities being completed at the same time will either take longer or not be completed to the same degree of success (i.e. cognitive activity becomes less efficient (Eysenck, Payne & Derakshan, 2005). Eye movements, as has been noted, have become increasingly frequent in the investigation of cognitive processing, and the activity of fixation durations, in all trial types, is of particular interest.

A potential explanation of the increased fixation durations may be found in the classic models of anxiety (e.g. PET/ACT, Eysenck & Calvo, 1992; Eysenck, Derakshan, Santos & Calvo, 2007), in which anxiety acts as an additional drain on cognitive resources. In such models, while one or several tasks might still be performed, there is a cost in overall efficiency (for example increased error rates or RTs), which is due to the drain in attentional ability (Eysenck, Payne & Derakashan, 2005). In other words, it is possible that the knowledge of a potentially hazardous situation provoked by the inhalation results in fewer resources being diverted to the search task at hand. This has resulted in increased fixation durations, as the search processes guided by attention are less efficient than previously seen, and more time is needed to acquire the same information in a non-stressed scenario. The effect of anxiety upon fixation durations is not a completely novel finding, and reflects earlier work, in that while individuals who have high levels of trait anxiety do not make more frequent errors in an anti-saccade task, there was an increased saccade latency (fixation prior to an eye movement), reflecting that increased processing was required in the planning of an eye movement (Derakshan, Ansari, Hansard, Shoker & Eysenck, 2009). However, the effect has not previously been tested within a search task in naturalistic scenes. The fact that lengthening of fixation durations occurs over all trials implicates a general information acquisition deficit, rather than only applying to target recognition. Therefore, while classic models of the effect of anxiety on cognition usually refer to reaction times or accuracy as a measure of efficiency (Eysenck et al., 2005) it would also appear to have a detrimental effect on visual processes, leading to increased fixation durations and either poorer learning of target identities or decreased confidence in search ability. If confidence in search ability were compromised then it is likely that we may have expected a greater number of fixations and longer RTs in target absent trials also, so in the absence of this finding it can be concluded that the process of learning targets itself has been affected.

Naturally, there are some drawbacks of this research design, particularly in participant sampling. In order to ensure that participants were not put in an unnecessarily unpleasant situation, a strict screening procedure was used that excluded participants who were most at risk for an adverse reaction to the CO_2. These measures, while in the best interests of the participants, substantially reduced the number of people eligible to take place in the study. Of the 24 participants who passed screening (out of 95 applicants), only 16 participants completed both of the breathing conditions. It is certainly conceivable that the participants represented in the data may have had lower traits of anxiety than in a random sample of the population. While it is not possible to establish this for a fact, it remains a possibility that the participant group may have been, on average, less prone to anxiety than participants taken in a random sample.

Another practical drawback of this research is that, due to the time length of the intervention, it is not recommended to complete the 7.5% CO_2 breathing task for an extended period of time (i.e. longer than 20-30 minutes, with levels of anxiety increasing as the time spent completing the task increase). As the earlier versions of the repeated scenes experiment could take between 40-50 minutes to complete, the number of scenes in a route sequence (40, see Tew et al., in prep) was halved in this version of the RSST. This was done to maintain the number of repeats of the scenes and target positions, but effectively made the task comparably easier, with only ten scenes having targets within them consistently, and only five specific locations that had recurring targets.

While these issues may make the effects of induced anxiety harder to detect, there are still clear effects upon search behaviour. The trends towards increased error rates, fixation durations and verification times all indicate that search efficiency is compromised in the presence of induced anxiety, and ultimately imply that in high risk scenarios (baggage scanners, x-ray or radar operators, soldiers or police officers on patrol, CCTV monitors) anxiety may be a contributory factor in poor decisions. In fact, due to the screening procedures, the impact of state anxiety on these decision processes may even be underestimated. This has been evidenced in the shift in criterion, but what is potentially more alarming is that certain individuals (i.e. those with higher levels of anxiety) may be less able to shift their decisions with experience, which leaves a potential danger for a higher number of incorrect decisions to be made, even in the event that anxiety is not actually present.

Chapter 5 General Discussion

5.1 Introduction

There were two key questions explored in this thesis. First, does knowledge of the forthcoming environment influence or improve the search for targets? Secondly, which cognitive processes and psychological attributes are most strongly associated with an ability to use or hinder the benefit of knowledge of the forthcoming environment to impact search?

These questions were explored using a novel experimental paradigm which was termed the Repeated Scenes Search Task (RSST). The RSST presented images of scenes taken while travelling along a route. Participants were instructed to search for targets while their eye movements were being recorded. The set of 40 scenes that formed routes were repeated eight times. The empirical findings showed that performance (in terms of RTs and accuracy) improved with blocks. This improvement was found in all conditions, regardless of whether target presence and location varied across repetitions of scenes or did not (Chapter 2; Experiments 1-3). The improvement was observed both in the initial experimental session and in a second follow-up session that took place 15 days later (Chapter 3). The improvement in RTs over blocks was also found when state anxiety was increased through participants inhaling a gas containing 7.5% CO_2 (Chapter 4, Experiment 1). However, the CO_2 challenge did remove any overall improvement in error rate over repetitions. The speeding of RTs over repetitions was also reflected in the eye movement data, with corresponding effects of the number and duration of fixations, and the time to initially fixate and confirm target identities in all experiments. The task, therefore, reliably showed some benefit to searching for targets that were repeatedly shown in the same scenes.

Below, I focus on the general pattern of results presented in Chapter 2. Two variations in the methodology separate these experiments from the rest of the thesis. First, the balancing of the consistent order of scenes forming a predictable route, which also appears in Chapters 3 and 4, against a randomised order of presentation. Secondly, across Experiments 1-3 in Chapter 2, the placement of targets varied from randomised (Experiment 1) to constrained to both scene and position (Experiment 3).

5.2 Chapter 2

Comparison of consistent and randomised conditions revealed only one difference across all the behavioural and eye movement measures tested, and which only appeared when targets could be fixed to specific locations in scenes (i.e. in Experiment 3). This was in the decreased likelihood of fixating targets before responding target-present when scenes were presented in the consistent order. While a modest effect, it is possible that the contingency of targets to scenes and locations supported participants in adopting a wider functional field of view. The result implies that ordered scenes in the real-world environment *may* prepare participants, but to do so the contingencies linking targets to scenes and locations in scenes must exhibit striking predictability.

Consideration of the individual difference measures challenges the conclusion that consistent scene order had a minimal influence on search performance, relative to randomised scenes. Of particular interest are the rates of learning measured through eye movements which were correlated against the cognitive faculties of the attentional networks and visuospatial and verbal WM. The analyses conducted in Chapter 2 revealed that individuals produced different slopes of learning across routes, depending on the route order and target contingencies. The orienting network (Fan et al, 2002) was found to be of key importance in consistently ordered scenes when target presence was unpredictable (Chapter 2; Experiment 1). The alerting network was implicated when targets were predictable and when the scene order was randomised (Chapter 2; Experiment 3).

These results confirm that the consistent order of scenes produced a measure of association between the scenes for participants with high orienting networks (as there was no corresponding benefit when the scenes were presented in the randomised condition). They also raise the possibility that the failure to find differences in the group analyses of RTs and error rates across conditions (consistent/randomised order) may be due to the differences between individuals in those groups. For example, it may be the case that for those individuals in whom the orienting network is particularly strong, the layout of scenes in the consistent condition only provides an advantage on occasions where there are no other contingencies associated with targets. However, when target locations can be predicted, but scene order is completely unpredictable, participants with a strong alerting network have an advantage in swift and efficient target detection.

These contrasting effects of orienting and alerting on improvement in target detection represent indirect evidence of an effect of scene order. While this evidence is in the form of associations, the fact that these associations exist raises concerns as to whether the randomised condition represents a neutral control comparison. In fact, there is a concern that the inclusion of randomised and consistent conditions may have encouraged participants to adopt a strategic approach to the RSST that enhanced (or inflated) the role of orienting and alerting attention on performance improvement. This possibility is discussed further below.

In contrast to the association of orienting and alerting attention with performance improvement over blocks, the experiments in Chapter 2 found no influence of either visuospatial or verbal working memory capacity on performance improvement over blocks. This null result may imply that WM is not associated with improving target search over blocks. However, comparing correlations across Experiments 1-3 does suggest some evidence of a trend for WM to become more strongly associated with performance improvement as the contingencies linking targets to scenes and locations become stronger (the correlations rise from .101 to -.315 and from .059 to .384, from Experiments 1 to 3, consistent and randomised conditions respectively). While not reaching significance, the contrasting difference in associations between consistent and randomised conditions was of empirical interest and suggested further exploration of the relationship between WM and performance improvement was of value. Chapter 3 reported a study that further explored the role of WM in supporting performance improvement.

5.3 Chapter 3

In this chapter, the RSST repeated the target conditions of Experiment 3 in Chapter 2 (but without the inclusion of a randomised condition) in an initial baseline session. Following this baseline session, participants engaged in an intervention phase where WM was enhanced using adaptive n-back training or transcranial direct-current stimulation (tDCS). After the intervention, participants repeated the RSST, but using a different route to that seen at baseline. There were three key sets of findings. First, the results at baseline replicated the pattern of performance improvement over blocks in the behavioural and eye movement measures, as reported in Chapter 2. Secondly, in contrast to Chapter 2, there was an association between visuospatial WM and performance improvement over blocks, but no association with orienting or alerting network strength. Specifically, the speed of correct responses in change detection, rather than overall accuracy, predicted initial performance on the task. Finally, while adaptive WM training improved verbal WM, there was no evidence of a specific benefit to performance on the RSST, beyond that of basic improvement through practice. Furthermore, there was no evidence of any impact of tDCS on WM or on the RSST, although performance improved with practice when returning to the lab following the 15-day break, as in the WM training group.

The results from Chapter 3 are of interest in four distinct regards. First, the performance improvement over blocks found in the Experiments 1-3 reported in Chapter 2 was replicated. Second, the concern that the inclusion of a randomised condition in Chapter 2 may have had a negative influence on performance by altering participant's strategy received some support. This support comes from the switch in associations, with performance improvement based on orienting and alerting network strength to visuospatial WM measures as being influential in search. Third, training, or otherwise trying to enhance WM through tDCS, does not lead to further performance improvement on the RSST, beyond that occurring with practice. Fourth and finally, the fact that performance improved from baseline to post-intervention sessions suggests that none of the effects reported in Chapter 2 or the baseline condition of Chapter 3 are compromised by floor effects in learning. Participants continue to learn from routes and targets, when they have the opportunity to.

5.4 Chapter 4

In the final empirical chapter I investigated a critical question with regards to applying the findings from Chapters 2 and 3 to the real world. The experiment reported in Chapter 4 explored how induced state anxiety affected the performance improvement consistently found across blocks in Chapters 2 and 3. Using physiological and psychological measures, the findings demonstrated that the CO_2 inhalation technique reliably induced increased levels of state anxiety. As a result, when in an increased state of anxiety, participants made more errors, their fixation durations were longer and they took more time to make decisions about targets (i.e., increased target verification time).

Importantly, the longer fixations and verification times found with increased state anxiety did not lead to longer overall RTs. In addition, with respect to error rates, the effect of increased state anxiety was to remove the performance improvement over blocks which had been reliably found in all other experiments. Overall, increased state anxiety appeared to influence the manner in which search was conducted. While overall search times were unaffected, some indices suggested a change in eye movement behaviour leading to a failure to improve targets detection over blocks. The analyses further suggested that increased state anxiety resulted in a conservative, perhaps inflexible approach to changing response criteria over time. In contrast, when participants were not in a state of anxiety, the criterion shifted with block to reduce the number of false alarms. The implications of these results are of critical importance for tasks where target search is conducted in high-threat environments.

5.5 Relating the findings to the issues outlined in the Introduction

This thesis and the experiments within it were driven by two key questions regarding the ability to predict forthcoming scenes: 1) does knowledge of the forthcoming environment influence or improve the search for targets and 2) which cognitive and psychological factors best support or hinder this ability? In the introduction, the issues that were identified as pertaining to these questions were grouped into three key areas: the impact of top-down contextual knowledge on search processes (which would define the knowledge of upcoming scenes), the cognitive networks supporting search and learning processes, and the differences between individuals in how they may perceive scenes and utilise these cognitive resources. In order to answer the two questions, the following sections will consider the way in which the empirical findings presented here fit within these key areas of interest.

5.5.1 Search in repeated routes

To address the first question, it was expected that the opportunity to prepare for scenes before they were viewed would provide an inherent advantage in both search and learning. The existing literature suggests that the greater context available to aid search (Brockmole & Henderson, 2006a,b), the more efficient that search will be, and therefore knowledge of scene identity prior to its presentation may provide an additional benefit to search performance. The experiments presented here show consistent findings suggesting that top-down contextual knowledge continuously enhances search in scenes: the more frequently targets and scenes are repeated, the faster search becomes. Similarly, the greater the context that can be related to a single scene identity, the greater the benefits to search efficiency, with not only faster RTs, but a higher number of found targets when locations can be predicted by scene identity. This is, in part, a replication of earlier work in contextual cuing (Chun & Jiang, 1998; Brockmole & Henderson, 2006 a,b). The experiments presented in this thesis also show that while contextual cuing still occurs in static scenes, which are either presented randomly or in a temporal sequence, there is no additional benefit resulting from the consistent presentation of scenes for either RTs or accuracy.

In spite of the lack of a main benefit to either search times or accuracy, there are reasons to reject the conclusion that consistent ordering did not affect search. Considering these scenes are presented as static, and what we know of the ability to process scenes quickly (VanRullen & Thorpe, 2001; Castelhano & Henderson, 2008) and with an immeasurable capacity for static images in long term memory (Standing, 1973), one potential explanation presents itself. It may be that, while scenes presented in a consistent order might aid search or the prioritisation of search areas (e.g. the orienting network, Chapter 2, Experiment 1), the processes supporting quick identification of scenes from memory might account for the efficiency in recognising scenes and utilising earlier memories of search to aid prioritisation (Chapter 3, baseline session). In other words, it may be that scene ordering does provide an advantage, but the ability to quickly recognise random scenes also provides a near-equivalent advantage in search.

A second crucial point with regard to the impact of context informing search rests in the likelihood of fixating a target prior to correctly identifying it. In Chapter 2 (Experiments 1-3) the likelihood of fixating targets decreases with block in all versions of the RSST and in both sequence conditions. However, in Experiment 3, where the greatest guidance for target position could be inferred from the scene, there was also a significant decrease in the likelihood of fixating targets in the consistent ordered sequence. Therefore, it could be the case that when searching within scenes in a consistent route, the ability to associate scenes with target locations (i.e., a version of contextual cuing) allows for enhanced processing from peripheral vision. Considering that both attentional guidance, and even target identification is possible beyond the fovea (Pollatsek, Rayner & Collins, 1984; Posner, 1980), the finding that the context of a route can aid in target identification from a distance is an important one for understanding the difference between visual search in static scenes and in the real world. A large number of existing eye movement studies have used static images with little or no relation to each other. However, if online processing that informs decision making also utilises past or expected future scenes to aid in target identification, then it is possible that the context of surrounding trials can have an indirect effect on the present trial. This may potentially have a greater impact in search within real-world scenes, where context is shown to be a key influence on performance. What lends this possibility extra weight is that it is only when the locations in scenes and targets can be linked in such way that there is a significant performance advantage when scenes appear in the consistent order of a route. Therefore, in static scenes contingencies to targets must be highly salient to offer any kind of advantage when they are presented sequentially.

The influence of scene order on search is present in these studies, but only in subtle ways, and only within specialised conditions. The empirical findings presented in this thesis outline an additional important influence on search performance: that of differences between individuals and the way in which cognitive factors related to memory and attention influence search.

5.5.2 Cognitive and psychological influences of search in real-world routes

When examining the effect of attentional and WM resources on learning via eye movement measures across Chapters 2-4, three key components were identified that explain some of the variance between participants. These are visuospatial WM and the orienting and alerting networks. Not only do these resources explain variance in search performance between individuals, but they also influence how scene order is perceived, depending on the prevalence and location of targets. When scene order is consistent, but targets are not, then the orienting network improves learning in both target present and absent scenes (Chapter 2; Experiment 1). When, however, scene order is randomised and targets are fixed in position, the alerting network provides an immediate improvement in performance. It would therefore appear that these cognitive resources facilitated the ways in which consistency in scene order was perceived between participants.

In all of the experiments reported in Chapters 2-4, the effect of the orienting network upon search performance was only a significant factor once, in Experiment 1 (Chapter 2). In both target present and absent trials there was enhanced learning when there was order to scenes, but no contingency to targets. In other words, when targets could appear anywhere (within the natural construction of the scene) then the ability to orient your attention around the environment effectively reduced both the number of fixations before reaching a target absent response and the identification of a target once it is fixated. This finding is of crucial importance with regard to the literature and real-world application of search tasks, as it indicates that some individuals will, without prior knowledge of scenes or targets, be able to pick up cues from the target to search more efficiently. It is likely then that the orienting network directs and facilitates attention both within known and within upcoming environments.

Within the experiments in Chapter 2 there were minor effects of visuospatial WM when targets were placed in consistent locations within scenes, and within the randomised and consistent sequences. It should be noted that the only scenario in which visuospatial WM became close to significant was when scenes could predict target location. When the randomised condition was removed from the methodology (Chapter 3, baseline session) visuospatial WM becomes a strongly significant factor in improved performance in search. Finally, attempting to train WM deployment didn't significantly improve performance (beyond practise), however it should be noted that only verbal WM appeared to be enhanced in only one of two interventions. Verbal WM has, at no stage in these experiments, been shown to enhance the search for targets in repeated scenes.

A second finding of interest from investigations of the cognitive components that support search was the alerting network did not significantly influence search performance in Chapter 3. The key difference in methodology would indicate that the only time the alerting network provided a unique benefit of search in Chapters 2-3 was when scene order was not predictable, i.e. when targets appeared in consistent locations, but without cueing the following scene. These results indicate that, during uncertainty in the environment, the alerting network can provide an advantage when there are *some* contingencies, however it is not a strong influence in a scenario where both the environment and target locations are stable.

While the effects of scene ordering have been hard to show with static scenes, the research findings reported here have shown that individuals perceive and search environments in different ways. This is an important point for the literature, as the majority of search studies can be said to be concerned with either factors drawn from the scene (bottom-up) or from the individual's knowledge (top-down). However, cognitive, rather than knowledge-based influences upon search have often been overlooked. Throughout the studies presented in this thesis, the difference between individuals has been shown to have a similar influence on both how well they search, and on how they will *improve* that search with experience. What has clearly been shown is that the orienting network is of importance when the environment is stable, but there is no contingency between targets and scenes (which is often the case in the real world). This, perhaps, provides a framework from which to build initial context. Perhaps we need to know what the environment will look like with some detail before natural contextual cuing can provide an additional benefit, beyond that of basic search behaviour (i.e. looking until you find the target, without any context on where it may be).

The importance of cognitive resources (like the attentional networks) with regard to search becomes of even greater interest when additional processing demand may disrupt efficiency. This additional processing demand may come in the form of increased anxiety. Based on the known negative influence of anxiety on performance (providing that the anxiety-inducing stimulus is not task-related), it was expected that the induced anxiety in the study reported in Chapter 4 would have a detrimental effect on search and learning. This was conclusively shown, both in increased error rates and in less efficient eye movements. What was surprising, however, was the effect of completing the task in the session in which anxiety was *not* induced. For some participants during this task, the lack of improvement was comparable with completing the session in the anxiety condition. Recall that during the experiment in Chapter 4 participants wore a gas mask in both inhalations, and were not told which inhalation would contain the CO_2 enriched gas. They were therefore completely aware that there was a 50% chance of receiving the active trigger of anxiety in each inhalation. In the presence of anxiety, participants were more likely to make mistakes, and the alerting network responded to the onset of signals, whether they were legitimate targets or not. The increased false alarm rate and the inability to learn from previous trials may be due to the fact that an overactive alerting network is responding to distractors and processing them as legitimate targets in the visual field.

Overall, the findings reported in Chapters 2-4 suggest that the influence of attentional networks can change the way in which participant search scenes and routes. Attentional orienting and alerting have been shown to be of particular importance in visual search, especially when elements of the environment are unknown. The impact of these cognitive resources, and how exactly search does improve in repeated routes, is considered below with respect to real world application of this research.

5.6 How does search improve in repeated routes?

The individual findings of these experiments point towards an interesting new account of how search and memory for targets and scenes is influenced by target contingencies, visuospatial WM resources and attentional networks. When targets can be found anywhere, the orienting network is of importance in improving search efficiency in a learnt environment. When the opportunity for learning target positions is high (i.e. when target location and presence can be predicted in advance of the current scene) and when potentially distracting (i.e. randomised condition) or anxiety provoking influences are low, then visuospatial WM facilitates improved decisions both with and without targets when the environment is stable. When there are either randomised elements in environment structure, or the threat of anxiety is present, two events occur. First, visuospatial WM no longer facilitates learning processes (or rather, learning processes do not depend on individual visuospatial WM strength) and the attentional networks begin to take on a greater role in learning targets.

It should be noted that within the context of a dangerous environment, for example when many disregarded items could contain explosives (IEDs) or numerous windows in a building could hide snipers, then the finding of a non-shifting criterion would mean that the likelihood of a miss is diminished, while false alarms do not decrease. If this means that attention is called to potential threats, and that cautious behaviour is engaged, then the likelihood of the individual to remain alive and unharmed may actually be increased. Anxiety has been previously described as the deployment of attention when in the presence of threatening stimuli, with a result that attention will be drawn to those stimuli while completing a separate task. In the hypothetical example of a soldier or police officer engaging in a search task, the presence of anxiety may lead to a higher number of false alarms. While in a simple target detection task this is seen as excessive errors, within the real world the false alarms could be interpreted as the need for closer scrutiny of the sought items, which is a sensible precaution if some of those targets are dangerous. If, however, the presence of anxiety had led to an excessive number of misses, then this would be a cause for great concern. A large number of false alarms, by themselves, are not going to provide a great threat to a soldier's life, but a single miss could precipitate the end of it.

However, the decision process that supports ongoing search cannot be distilled into a single false alarm or miss. It is the active continual search and feedback of previous searches, which is important to maintain. Excessive false alarms facilitated by an overactive alerting network (e.g. examining every single object on the path ahead) would be a short-sighted measure of ensuring safety, as this technique will severely slow progress, which in turn would make the likelihood of a different form of danger more likely (such as those meaning you harm being drawn to your position). Therefore, in signal detection terms, there must still be a reasonable amount of certainty placed on numerous targets (e.g. criterion), with the acceptance that there is a slim probability that a miss may occur, even with a very conservative criterion threshold. This does not actively mean to suggest an improvement in signal detection in this task, but in the real world it can be extrapolated to reflect a self-preservation instinct. By not reducing the chance of false alarms, the probability of a miss is theoretically more unlikely. The fact that these findings occur within the context of anxiety is closely tied to the effect of anxiety on WM faculties.

5.7 Future directions

There are several directions in which this research could continue. It has been established that a static presentation of scenes, while allowing for an easily achievable balance with a control condition, does not allow for a distinct advantage in search efficiency, when discussing RTs and error rates. Of two avenues that future research could pursue, the first would be an extension of the current paradigm in which the number of repeated blocks would be increased, perhaps as high as 20 presentations. This would establish whether simply presenting static images without a cue or route context allows for the same amount of learning that is presented with the context of a route. However, considering the ability for participants to recognise scenes very quickly and the durability of long term memory, it is likely that simply presenting more iterations of the routes as has been achieved in Chapter 2 would not produce a difference in group results, other than establishing a plateau in performance measures. In other words, presenting more opportunities to learn would only provide for general improvement, rather than a unique advantage in the consistent route.

The second avenue of research would be to design a considerably more immersive experiment, as there is some consideration for the theory that the reason for a lack of unique improvement in the consistent route could be due to the fact that static images do not fully represent the experience of walking. The challenge with such a paradigm would be to construct a scenario in which isolated portions of a conceptual route can be said to only present a limited context (the scene itself). If, for example, video footage of a long route was isolated into clips of only a few seconds to provide the background for search, would the 5-second clip be sufficient context to provide an equal advantage to presenting the route in full? The inherent issue with utilising any context are the boundaries defining that context.

One solution may involve utilising immersive presentation technology, such as virtual reality (VR) headsets. This would allow the possibility of presenting a series of computerised environments to the eyes which may enhance the feeling that the participant has agency within each scene. As it has also been possible to link eye movements with stimuli received in VR presentation screens (Binaee, Diaz, Pelz, & Phillips, 2016; Skulmowski, Bunge, Kaspar, & Pipa, 2014), then the way in which participants search through their environments in a much more immersive way is an area very likely to be explored in future research. If this immersion and agency is established, it may be easier for participants to link such environments to each other, and then contextual effects of the global environment may provide a greater advantage in future searches. If the experiments were repeated with a more immersive environment then the effects of visuospatial WM, and the alerting and orienting networks may also be enhanced further.

A second question that could also form the focus of future research is how the attentional networks may compensate for WM processes (particularly visuospatial WM), as well as allow participants to search with greater efficiency. As with any experiment that attempts to explore differences between individuals, research conducted with this aim should recruit a higher number of participants, particularly when engaging in any question of individual tolerance to state anxiety. The full extent of the attentional networks compensating for WM processes could be investigated in future research, as it should be noted that the number of participants that contributed to the data is possibly too small to make sweeping assumptions. This applies in all of the chapters, but particularly within the context of Chapter 4. Importantly, the small number of participants who were eligible to take part in the experiment and were able to complete the CO2 challenge (16 out of 95) could potentially be particularly resilient to the effects of trait and state anxiety.

5.8 Conclusion

This thesis aimed to answer two key questions of relevance both to the scientific literature and for those who conduct searches in potentially dangerous environments. Those questions were: 1) does knowledge of the forthcoming environment influence or improve the search for targets and 2) which cognitive and psychological factors best support or hinder this ability? It has been shown throughout the empirical studies presented here that there are individuals who can utilise scene order to their advantage. Participants who have high levels of orienting network strength are better able to use the surrounding environment to find targets when no contingency to target location exists. Additionally, in the absence of randomised elements in presentation, visuospatial WM is of clear benefit when targets can be reliably found in scenes. Critically, the influence of anxiety has a detrimental effect to search, with both increased errors and less efficient eye movements. This is of particular importance when conducting search in dangerous environments. What is, perhaps, of even greater importance is that for some individuals the *threat* of anxiety is enough to disrupt learning in routes. Overall, the empirical findings presented in this thesis suggest that it is possible to use the environment ahead to influence search, and the way in which this benefit manifests depends on a number of cognitive (attentional networks & visuospatial WM) and psychological (levels of or tolerance against state anxiety) influences. Thus, in order to fully understand the process of visual search in the real world, and particularly in dangerous environments, it is necessary to carefully consider the complex interdependencies between these different factors.

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